CORPS-WIDE CONFERENCE ON

COMPUTER AIDED DESIGN IN STRUCTURAL ENGINEERING

22-26 September 1975

VOLUME V
GRAVITY MONOLITHS, U-FRAME LOCKS, and CHANNELS

Edited by N. RADHAKRISHNAN

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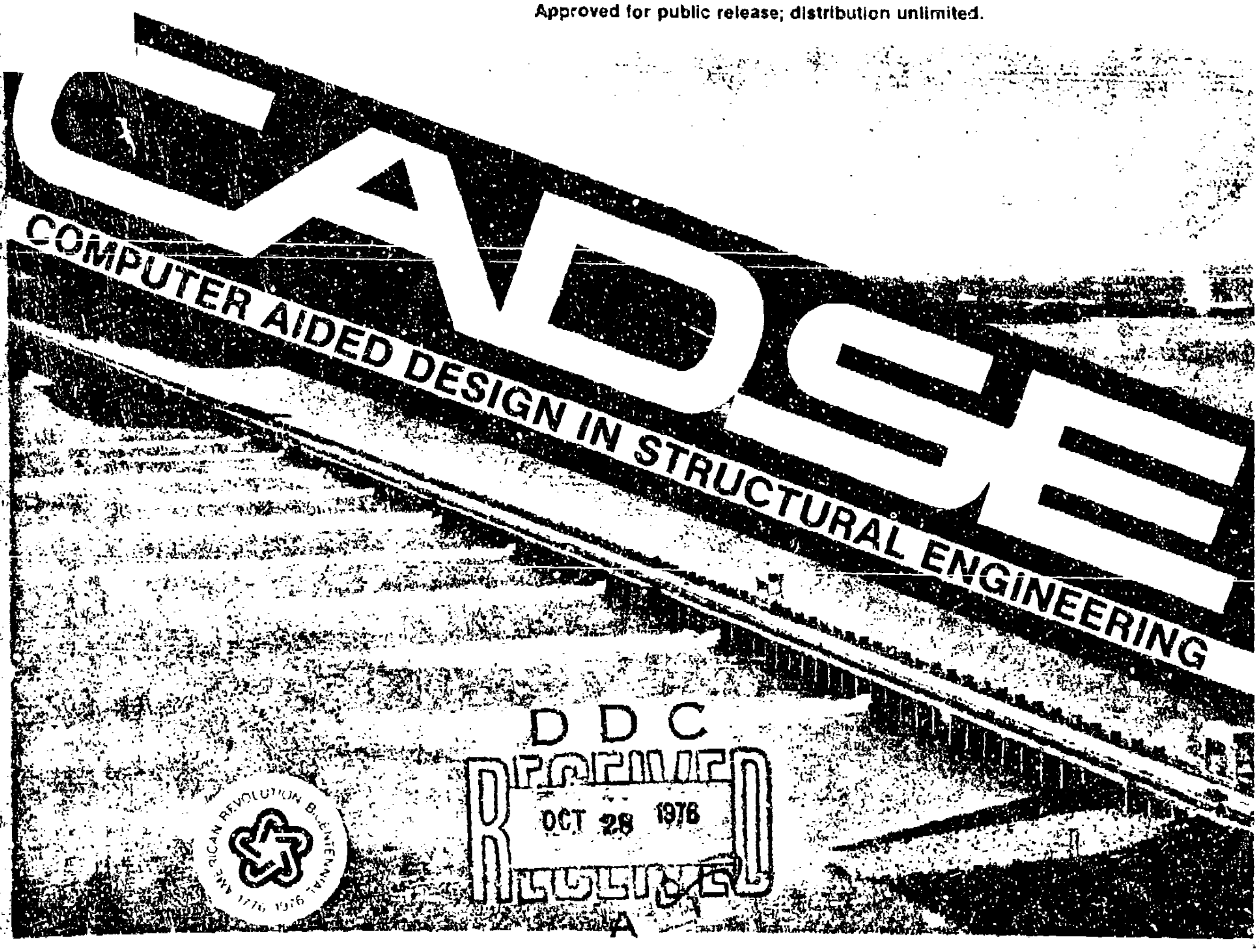

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

GRAVITY MONOLITHS: Gravity monoliths are used for dams, navigation locks, and retaining walls. The structural design of gravity monoliths includes evaluation of foundation conditions and spillway and freeboard requirements and the application of loadings to determine stability against sliding, overturning, and internal stress conditions. Loads are determined as directed by EM's 1110-2-2200, -2400, -2502, and -2602. Loadings include weight of the structure, water, uplift, silt and fill, wind, wave, ice, and seismic and construction

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20. ABSTRACT (Continued).

loads. Loads are combined to establish the worst possible conditions. For stability, it is required that the monolith be safe against overturning at any horizontal plane within the dam, on the foundation, or on any horizontal or nearly horizontal seam in the foundation. The allowable unit stresses in the concrete or in the foundation material must not be exceeded. Finite element analysis is the best way to determine internal stress. Computer programs can determine loads and design simple monoliths and can analyze and review complex systems. The simpler programs replace slide-rule computations; the more sophisticated programs do analyses that cannot be manually performed and provide more exact results. This paper lists and discusses the available programs for gravity monolith design.

U-FRAME LOCKS: Navigation locks improve river navigation by decreasing river gradients and increasing water depths. Although U-frames allow greater diversity in design and placement, gravity monoliths, because of their simplicity in design and construction, have been used in the United States almost to the exclusion of the U-frame monolith. U-frames have, however, been used successfully by the Corps. They seldom require piles, special foundation treatment, or elaborate drainage systems. The U-frame lock chamber can be unwatered safely at any time with a minimum number of dewatering wells. When used as gate bay monoliths they can minimize differential settlement, undesirable tilts, and the resulting possibility of gate damage. The principal elements of design for a U-frame section consist of insuring safety of chamber sections, determining stresses at center of vase and at its juncture with chamber walls, and analyzing culvert frame and stability of sidewalls. The design is based on two main loading conditions, lock empty, and lock full, with other conditions considered as needed. Assumptions regarding pressure distributions are most important. Design computer programs based on slope-deflection, moment distribution, and similar elastic frame theory have been used to precede analysis by the finite element method. Since all existing finite element U-frame codes have limitations, the designer should consider logic and experience when using them. In this paper available computer programs for U-frame design are evaluated and recommendations for improvement made.

U-FRAME CHANNELS: At least nine different computer programs are used by the Corps of Engineers in the analysis and design of U-frame channels. This report gives program abstracts and evaluations of five of them. The report also offers a few comments on the present state of Corps use of computer programs for design of U-frame channels.

PREFACE

In December 1974, the Automatic Data Processing (ADP) Center, U. S. Army Engineer Waterways Experiment Station (WES), submitted a proposal to conduct a Corps-wide Conference on Computer-Aided Design in Structural Engineering (CADSE) to the Office, Chief of Engineers (OCE). OCE approved the proposal and efforts were started in February 1975 to conduct this Conference. The Conference was conducted in New Orleans, Louisiana, 22-26 September 1975 and was attended by 175 engineers from 48 Corps field offices, OCE, Construction Engineering Research Laboratory (CERL), and WES.

This volume contains the papers from Speciality Session A, State-of-the-Corps-Art on Gravity Monoliths and U-Frame Locks and Channels. Mr. Charles M. Hargett, Chief, Inspection & Evaluation Section, LMKED-DI, Vicksburg District, was session chairman and presented a paper. Other papers were presented by Mr. Norman W. Wilke, Structural Engineer, NPWEN-DB, Walla Walla District, and Mr. James W. Simmons, Chief, Structural Section, NABEN-D, Baltimore District.

This is Volume V of the Proceedings of the Conference. Other volumes of the Proceedings listed below are also being published:

Volume I:	Management Report
Volume II:	List of Computer Programs for CADSE
Volume III:	Invited Speeches and Technical Presentations
Volume IV:	Division Presentations
Volume VI:	SOCA Reports on Gates, Stoplogs, and Trashracks
Volume VII:	SOCA Reports on Single- and Multiple-Cell Conduits and Tunnels
Volume VIII:	SOCA Reports on Pile Foundations and Sheet Pile Cells
Volume IX.	SOCA Reports on Sheet Pile Walls and T-Walls
Volume X:	SOCA Reports on Stiffness Methods, Frames, and Military Construction
Volume XI:	SOCA Reports on Earthquake and Dynamic Analyses
Volume XII:	Interactive Graphics, SEARCH and CORPS Systems

The Conference was successful due to the efforts of a multitude

of people. The roles they played were different but they were all directed towards making a concept on "instant dissemination" work. The Organizing Committee for the Conference consisted of:

COL G. H. Hilt, WES
Mr. F. R. Brown, WES
Mr. D. L. Neumann, WES
Mr. J. B. Cheek, Jr., WES
Dr. N. Radhakrishnan, WES - Conference Coordinator
Mr. W. A. Price, WES
Mr. G. S. Hyde, WES
Mr. D. R. Dressler, LMVD
Mr. W. B. Dodd, LMNDE
Ms. E. Smith, LMNDE
Mr. L. H. Manson, LMNDE

An OCE Coordinating Committee also worked enthusiastically to ensure the success of the Conference. This Committee consisted of:

Mr. C. F. Corns
Mr. R. L. Delyea
Mr. R. F. Malm, OCE Coordinator
Mr. L. G. Guthrie
Mr. D. B. Baldwin
Mr. R. A. McMurrer

The New Orleans District did a remarkable job in playing hosts to the Conference.

There were 13 Division speakers, 25 moderators, two invited speakers, four technical speakers, and ten session chairmen who shared the technical load of the Conference. Also, eight computer vendors showed their ware to the participants.

The authors would like to thank all the individuals who served on the committees and the speakers and the moderators for sharing their time and thoughts. Without them the Conference would not have been the success it was. Mr. Donald Dressler, LMVD, and Mr. William Price, WES, are specially thanked for their technical guidance and assistance.

This report was edited by Dr. N. Radhakrishnan, Research Civil

Engineer, Computer Analysis Branch (CAB), and Special Technical Assistant, ADP Center, and Mr. J. B. Cheek, Jr., Chief, CAB, ADP Center, under the general supervision of Mr. D. L. Neumann, Chief, ADP Center.

The Director of WES during the Conference and the preparation of this report was COL G. H. Hilt, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

GRAVITY MONOLITHS

by

Norman Wilke*

General

Gravity monoliths are used for dams, navigation locks, and retaining walls. Design philosophy and procedure in the Corps as elsewhere, is "... to produce a structure that will be safe against failure and that will satisfactorily perform its intended functions as economically as possible."[1]**

Loads

After evaluation of foundation conditions and spillway and freeboard requirements, the structural design of gravity monoliths includes application of loadings to determine stability against sliding and overturning and internal stress conditions.

Loads are determined as directed by EM's 1110-2-2200, -2400, -2502, and -2602. Loadings include weight of the structure, water, uplift, silt and fill, wind, wave, ice, and seismic and construction loads.

Dead load. Dead load computations generally assume concrete with a unit weight of 150 pounds per cubic foot. Relatively small voids normally are disregarded except in low dams. Other dead loads would include the weights of appurtenances, such as gates or bridges and superimposed backfill.

Water. External water loads are usually the hydrostatic water pressure acting normal to the face of the structure, although the dynamic effects of the velocity of approach to an overflow spillway may require consideration in special cases. Tailwater, if present, is assumed at full value for non-overflow sections and "at about 60 percent

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* Structural Engineer, Walla Walla District, North Pacific Division.

** Raised numbers refer to entries in the References on page 13.

of full value for deep flow over the spillway."[2] The jet of water on an overflow section may in some cases exert pressure, normally ignored, on the structure, or create subatmospheric pressure, which may require consideration.

Uplift. Uplift is assumed within the monolith, at the contact plane between the monolith and its foundation, and within the foundation below the contact plane. Uplift intensities under the structure to be used in the design depend upon the foundation material, provision of effective drainage, and the function of the structure. Uplift pressure, under rock based monoliths with no drainage provided, is assumed to vary uniformly from full tailwater at the toe to full headwater at the heel. If drainage is provided, the intensity varies from full headwater at the heel, to a reduced uplift at the drains, and then to tailwater at the toe. If the drains are as far upstream as possible, the uplift is assumed to vary as a single straight line, as if the drains were exactly at the heel. For retaining walls resting on soil, uplift may be estimated through the use of flow nets.[3] For lock walls on piles in an impervious foundation, uplift is assumed to be the same as for walls not founded on piles; however, if the cutoff is at an appreciable distance from the high water face, full upper pool is to be applied on that part of the base on the high-water side of the cutoff. For lock walls on piles in a pervious foundation, uplift is full tailwater on the low-water side of the cutoff and full headwater on the high-water side.[4]

Uplift on any part of any foundation plane not in compression is assumed to be full hydrostatic head of the adjacent face unless zero compression is the result of an instantaneous loading, such as earthquake.

Uplift within the body of a concrete gravity dam is assumed to vary from 50 percent of maximum headwater at the upstream face to 50 percent of tailwater (if any) at the downstream face. Within lock walls the uplift is taken as full tailwater at the low-water side to full tailwater plus 50 percent of the difference between headwater and tailwater at the high-water side.

Navigation lock-gate sills are designed for uplift varying from

full low-water pressure to full high-water pressure, both on the base and within the body. Any portion of a horizontal internal plane not in compression is assumed to be loaded by a uniform uplift of full high-water head.

Soil. Soil pressure due to siltation and backfill must usually be considered. Depending on the rigidity of the structure and its foundation, the soil may exert active, arching-active, or at-rest pressure. If the soil is compressed horizontally, lateral pressure will increase to its passive pressure. Graphical methods may be required to determine pressures for cases involving irregular surfaces of the monolith or the fill and concentrated surcharge loads. Water in the soil causes a pressure on the wall equal to the effect of the buoyant weight of the soil plus full hydrostatic. In general, at-rest pressures are applied if wall movement due to rotation, member deflection, or foundation yielding will not reach 0.0005 times the vertical depth of the backfill at the wall. Otherwise, active pressures are to be used. Specific situations are included in the Retaining Walls EM.

Wind. Wind loads are assumed at 30 psf, placed to cause the most unfavorable effect on the analysis.

Waves. Wave pressure may affect a dam's stability. Dimensions and forces of waves are functions of the fetch, wind velocity, and other factors. Waves and wave pressures are discussed in EM's 1110-2-1608 and -2904.

Ice. Ice pressure, like waves, is more important in the design of gates and appurtenances than in the design of a gravity dam. A unit pressure of not more than 5,000 psf, based upon the expected ice thickness, is to be applied at the normal pool elevation. Ice thickness in the United States normally will be assumed not to exceed two feet.

Earthquake. Seismic forces include inertia forces due to the acceleration of the monolith and any superimposed dead loads, hydrodynamic forces from the reaction of water, and dynamic earth pressure effects. A minimum horizontal seismic acceleration of 0.10 g should be applied to structures built in regions where moderate and major damage due to earthquakes may be expected, and 0.05 g where minor damage is

expected. Vertical acceleration is normally ignored. A seismic risk map (included in Reference 5) is a guide for earthquake loading of hydraulic structures. Inertia forces are applied horizontally at the centers of gravity of masses, hydrodynamic forces are located according to Westergaard's parabola at 0.4 times the water depth above the bottom, and dynamic earth forces are applied at two-thirds the fill height above the base. Uplift is assumed unaffected by earthquake.

Miscellaneous loads. Loadings unique to the structure, such as hawser pull or barge impact on navigation locks or soil surcharges behind retaining walls, are to be included as appropriate.

Comparison with other designers' assumptions. In its assumed loadings, the Corps applies more severe uplift at or below the foundation when drains are provided than do other organizations. We assume uplift pressure to be tailwater plus 50 to 75 percent of the difference in heads at the drains; two organizations use 25 percent; two others use 33-1/3 percent.[1] On the other hand, our assumption of internal uplift through a dam monolith, varying from 50 percent of tailwater at the toe to 50 percent of headwater at the heel, is apparently less than the more commonly assumed full tailwater to full headwater.[1] No mention is made in our EM's of internal drains or open monolith joints to effect any reduction of uplift. The Corps normally ignores vertical acceleration due to earthquake; others do not.[6,7] The Corps increases static pressure of typical backfill material twice the percentage of the earthquake's acceleration (e.g., 10 percent for 0.5 g seismic); the Bureau of Reclamation claims earthquake acceleration "is only about one-half as effective in silt or soil masses as it is in water."[7] Our equations for hydrodynamic effects result in slightly larger forces than those used by the Bureau.

Load Combinations

Loads are combined so as to establish the most adverse conditions. For normal operating conditions the stability requirements are severe; for construction conditions they may be somewhat less stringent. For

combinations involving extreme operating, maintenance, and emergency conditions the criteria are relaxed somewhat more. Six load combinations are cited in the Gravity Dams EM; from two to four load combinations for spillway approach (chute and stilling basin walls are specified in the Spillway EM),[8] and from one to eleven for the various components of navigation locks.

Stability Requirements

General. The basic requirements for stability are:

a. That it be safe against overturning at any horizontal plane within the dam, at the base, or at a plane below the base.

b. That it be safe against sliding on any horizontal plane within the dam, on the foundation, or on any horizontal or nearly horizontal seam in the foundation.

c. That allowable unit stresses in the concrete or in the foundation material shall not be exceeded.

Overturning. The monolith is considered safe against overturning when the resultant of all forces acting above any horizontal plane falls within the kern of the plane; this is the criterion for normal operating loads. For walls on rigid foundations loaded with "at-rest" soil pressures, the resultant may fall outside the kern but should fall within the middle half of the base. If earthquake is involved, the resultant must fall within the base.

Sliding. Safety against sliding is determined by dividing the sliding resistance of the path being investigated by the horizontal loads applied to the structure. The resistance is a function of the angle of internal friction of the foundation material (or sliding friction as applicable), the vertical force, the unit shearing strength of the material, the area of the plane, and its angle with the horizontal. The passive resistance of a downstream layer of rock may, under certain conditions, be added to the sliding resistance. This shear-friction factor of safety must be at least four for all loading conditions which do not include earthquake; it should exceed 2-2/3 for loading conditions where earthquake is considered.[9]

Stresses. Vertical unit stresses at the foundation plane and in the body of the dam are assumed to vary in a straight line according to the formula $f = (W/A) \pm (Mc/I)$. (See Equation 5 of Reference 4 for nomenclature.) Inclined stresses and average shears, as computed according to the formulas of Reference 2, are required at several levels in dams of moderate height. For higher dams (more than 250 feet) a more complete analysis is required and stresses are determined according to Reference 10. Stress concentrations at the foundation, around openings or at abrupt changes in section, and miscellaneous stresses due to steeply sloped abutments, unusual foundation conditions, joint grouting, and temperature effects may require investigation. Finite element analysis is the most practical way to approach these problems. Concrete stresses in compression are limited to one-fourth the one-year strength for working loads. The early load and construction requirements should be satisfied. Concrete is generally assumed to have no tensile strength.

Other designers' criteria. Other organizations use slightly different criteria. Some require the resultant to fall within the middle half of the base when seismic forces are included; one limits foundation bearing pressure to 40 percent of the concrete's 28-day strength. One permits 15 psi tension at the toe for the construction condition of reservoir empty and 15 psi at one corner of a monolith for operating conditions having horizontal water or earth loads in two perpendicular directions. One organization limits tension to 15 psi at the upstream face when seismic forces are involved. Some use sliding safety factors of 4.5 to 5.0 for normal loads; some require 3 to 4 when earthquake is included.[1] The Bureau of Reclamation calls for varying safety factors, which depend on the loading condition and differ in the foundation from those used in the monolith or at its base.[11]

Role of Computers

Computer programs are used in the determination of loads, for the design of less complicated monoliths, and for analysis or review of more complex systems. The simpler programs automate the computations

previously done using slide-rules, practically eliminating casual error. The more sophisticated programs use more powerful analytic techniques for investigation and design than could be performed manually, simultaneously avoiding simplifying assumptions and providing more exact results according to theory.

Computer Usage

Response to the questionnaire circulated by WES indicates that 28 Corps districts and 3 divisions have designed or will design gravity dams or walls; all but nine report using a computer program. The programs have been divided into four categories: those for non-overflow structures, for spillways, for lock walls, and for stress investigation. Some may be used for more than one category. Divisions and districts designing gravity dams or walls and the computer programs they use are listed in Appendix A.

Non-overflows. New England Division's program 713-F5-DO-100 looks to be very nearly the ideal program for non-overflow sections. It applies the six loading conditions required by the Gravity Dams EM, handles sloping foundations, and modifies the structure to meet overturning and sliding criteria, if necessary. It is, however, limited to two dimensions in structural outline and loadings. To be more truly general, the program should be modified to incorporate at-rest soil pressures and the effect of earthquake on fill material. Alaska's program 713-K5-G1-040, also two dimensional, can incorporate foundation material and may also be used for overflow sections; it appears to need updating. Program 713-K5-G4-400 (Walla Walla) can be used for three-dimensional structures and tri-axial loading, but data input is lengthy.

Spillway. Program 713-F5-DO-105, by New England, performs the same for overflow weirs as does their non-overflow program. St. Louis's program 713-R3-A3-150 applies the six loading conditions to a spillway and pier monolith and analyzes overturning and sliding stability.

Lock walls. Mobile District's program 722-S8-K5-180 designs and analyzes lock walls on the basis of one-foot strips, although load cases

and earthquake effects are not in the program. Chicago's "Lockwall" program includes an earthquake analysis. Nashville's programs NS 02 1300 and 03 1300 do some designing but have restrictions built in.

Internal stresses. Stress investigation of internal horizontal planes according to straight-line stress distribution are performed by New England Division's 713-F5-DO-101 and Seattle District's 713-K5-G3-040. Finite element analyses are made easier if data generation is performed at least in part by the program, as in Walla Walla's 713-K5-G4-710. Data output is more easily viewed if stresses are plotted: either contours, as in Infonet's "Superb," or vectors, as in Walla Walla's 713-K5-G4-710. Three-dimensional finite element analysis is performed by SAP4.

Whole-structure programs. Programs which take the third dimension into account are New England District's 712-F5-DO-102 and Walla Walla's 712-K5-G4-400. The former is for non-overflows and does not handle transverse loads. The latter is a general program which can be used for almost any type of structure; data preparation is lengthy, some updating is required, and the user must be aware of the program's requirements for earthquake loadings.

Desired Features for Gravity Monolith Programs

Many of the programs discussed include some or all of the features desired. To my mind, an ideal program would include: (a) automatic application of load combinations required by the appropriate engineering manuals, (b) minimum input, (c) three-dimensional loading and resultants, (d) optimization capability, and (e) internal stress investigation. This ideal program is not beyond the reach of current technology.

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3. Department of the Army, "Retaining Walls," EM 1110-2-2502, May 1961, Washington.
4. Department of the Army, "Planning and Design of Navigation Lock Walls and Appurtenances," EM 1110-2-2602, June 1960, Washington.
5. Department of the Army, "Structural Design for Earthquakes," ETL 1110-2-109, Oct 1970, Washington.
6. Portland Cement Association, "Small Concrete Dams," 1971, Skokie, IL.
7. Bureau of Reclamation, "Design Standards No. 2, Concrete Dams," Reprint Sep 1966, Denver.
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10. Creager, W. P., Justin, J. D., and Hinds, J., Engineering for Dams, J. Wiley and Sons, New York, 1945.
11. Bureau of Reclamation, "Design Criteria for Concrete Arch and Gravity Dams," Engineering Monograph No. 19, Sep 1974, Denver.

APPENDIX A:

LIST OF CORPS OF ENGINEERS OFFICES DESIGNING GRAVITY DAMS AND WALLS AND THE COMPUTER PROGRAMS USED FOR DESIGN ASSISTANCE

Corps of Engineers Offices designing gravity dams or walls:

Divisions: New England, Missouri River, and North Pacific.

Districts: Alaska, Baltimore, Buffalo, Charleston, Chicago, Detroit, Fort Worth, Huntington, Kansas City, Little Rock, Louisville, Mobile, Nashville, New Orleans, Omaha, Philadelphia, Pittsburgh, Portland, Rock Island, Sacramento, St. Louis, San Francisco, Savannah, Seattle, Tulsa, Vicksburg, Walla Walla, and Wilmington.

Computer Programs available:

TYPE	PROGRAM NUMBER	OFFICE
Non-overflow Dams	713 F5 D0100	New England Division
	713 F5 D0102	New England Division
	713 K5 G3040	Seattle
	713 24 050	Pittsburgh
	713 G1 M0060	Tulsa
Overflow Dams	713 G1 K6370	Savannah
	713 R3 C1090	Kansas City
	713 R3 A3150	St. Louis
	713 F5 D0105	New England Division
	713 G1 M0050	Tulsa
Lock Walls	722 S8 K5180	Mobile
	713 H4 030	Pittsburgh
	713 F2 014	Chicago
	NS 02 1300	Nashville
	NS 03 1300	Nashville
Multi-Purpose	713 K5 G1040	Alaska
	713 K5 G4400	Walla Walla
Stresses	713 F5 D0101	New England Division
	713 K5 G3040	Seattle
Powerhouse	713 K5 G0010	Hydro-Electric Design Branch, North Pacific Division
Finite Element	713 K5 G3840	Seattle
	713 K5 G4710	Walla Walla
	SAP4	Waterways Experiment Station
	STRUDL	
	SUPERB	Infonet

Appendix B: Computer Program Abstracts

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM		PROGRAM NO.
Stability Analysis - Nonoverflow Gravity Dam		713-F5-D0-100
PREPARING AGENCY		
New England Division		
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE / STAGE
Paul R. Laliberte	June 1972	

A. PURPOSE OF PROGRAM

The program investigates sliding and overturning stability of a nonoverflow gravity dam section. As options, the program will increase the upstream slope or the depth of key in order to meet existing criteria. As a result, the most economical section may be found with a minimum of effort. Base pressures are also determined.

B. PROGRAM SPECIFICATIONS

The input is such that most any type of cross-section may be investigated, including one with a gallery. Water and earth can be located at any elevation on both the upstream and downstream sides. The structure may be on either a soil or rock foundation with or without passive pressure. Uplift reduction can be made.

C. METHODS

Conventional engineering techniques are utilized. The program has been prepared in accordance with criteria as set forth in EM 1110-2-2200 and ETL 1110-2-63. Standard programming methods in FORTRAN IV are used.

D. EQUIPMENT DETAILS

The program is written for a GE 427 (64K) computer and requires 4,644 words of memory in its present form. Components include an on-line card reader and printer and an off-line card punch.

E. INPUT-OUTPUT

Input is on punched cards and consists of a project title card, a station and case card, and pertinent data cards. Any number of stations and/or cases may be investigated.

Output provides a listing of descriptive data for the sections analyzed with an explanation of results.

F. ADDITIONAL REMARKS

The program has been successfully used for design of Trumbull Dam, Bloomington Dam, and the Lancaster Ice Dam.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
3-Dimensional Stability Analysis, Nonoverflow Gravity Dam			713-F5-DO-102
PREPARING AGENCY: New England Division			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Paul R. Laliberte	August 1971		

A. PURPOSE OF PROGRAM

The program investigates sliding and overturning stability of a complete monolith with either a horizontal or irregular shaped base. The unsymmetrical projected base area is analyzed for sliding parallel and perpendicular to the base line. Overturning is about the two perpendicular centroidal axes. Base pressures are found.

B. PROGRAM SPECIFICATIONS

Pertinent data is entered for the end sections of the monolith. An iterative process is used to compute forces on the monolith. Water and earth elevations may vary on the upstream and downstream sides. Either a soil or rock foundation may be specified and can include passive resistance. Uplift reduction can be made.

C. METHODS

Conventional engineering techniques are used.

The program has been prepared in accordance with criteria as set forth in EM 1110-2-2200 and ETL 1110-2-63.

Standard programming methods in FORTRAN IV are used.

D. EQUIPMENT DETAILS

The program is written for a GE 427 (64K) computer and requires 18,669 words of memory in its present form.

Components include an on-line card reader and printer and an off-line card punch.

E. INPUT-OUTPUT

Input is on punches cards and consists of a project title card, a monolith and case card, and pertinent data cards. Output consists of descriptive data for the monoliths analyzed.

F. ADDITIONAL REMARKS

The program has been successfully used for design of Trumbull Dam.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Gravity Dam Stability Program Non-Overflow Section (STABAN)	713-K5-G3-0[illegible]

PREPARING AGENCY

Seattle District

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Paul D. Breeding	Feb 1965		Op.

A. PURPOSE OF PROGRAM

"Staban", is a stability analysis program designed to give the Dam designing engineer a complete stability analysis for all six loading conditions as defined by the U. S. Corps of Engineers Manual EM 1110-2-2200, 25 Sept. 1958.

B. PROGRAM SPECIFICATIONS

FORTRAN II

C. METHODS

1. The monoliths' volume, center of gravity, dead load, point loads, and resulting moment about the heel for each zone pre-picked by the designers is computed and printed on output cards or stored for later use.
2. The routine is routed through the six loading conditions assigning the proper loading sequences, coefficients, and signs to the various terms.
3. Next, the external loads are calculated and combined with the dead load terms already found above for one loading condition and for one zone. Using this data, the overturning moment along with the other terms listed under "output" is calculated and printed on output cards.
4. The routine is then continued to the next lower zone and after repeating the above calculations is continued progressively through all zones.
5. Steps "3" and "4" are repeated until all six conditions are complete.

D. EQUIPMENT DETAILS

IBM 360/50

E. INPUT-OUTPUT

F. ADDITIONAL REMARKS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Gravity Dam Stability	713-F7-H4-050 (713-24-050)

PREPARING AGENCY

Pittsburgh District

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
L. R. Noy			Op.

A. PURPOSE OF PROGRAM

The program provides analysis of overflow gravity dam sections. Considers sloping bases and other uplift values at the toe.

B. PROGRAM SPECIFICATIONS

FORTRAN

C. METHODS

D. EQUIPMENT DETAILS

G-225 Batch

E. INPUT-OUTPUT

Input - Cards

Output - Printer

F. ADDITIONAL REMARKS

This program is originally from the Seattle District. Several revisions have been made by the Pittsburgh District and they are currently reviewing the program by comparing the results with a simple dam test problem and, in addition, is revising the program to calculate resisting forces on a sloping base as dictated by ETL 1110-2-184, 25 Feb 1974, "Gravity Dam Design Stability." Complete documentation is available.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Non-Overflow Stability Analysis			13-G1-M006
PREPARING AGENCY			
Tulsa District			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
F. Webster G. Henson	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes the information necessary to analyze the stability of a non-overflow section.

B. PROGRAM SPECIFICATIONS

The program is written in Card FORTRAN.

C. METHODS

Moments of forces applied to the structure were taken about the moment center. Forces applied in the analysis are dead load, external water pressure, earth pressure and uplift.

D. EQUIPMENT DETAILS

The equipment required is the GE 225 data processing system (8K storage) with GE card reader, 3 tape handlers, and GE high-speed printer.

E. INPUT-OUTPUT

Input is by cards, and output is on printer paper.

F. ADDITIONAL REMARKS

The input variables SX, SY, SKY, and SKX are scale factor for the plotter. These variables are to be ignored until the program is further developed to make use of the plotter.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM: Overflow Monolith Stability	PROGRAM NO.: 713-G1-K6-370
PREPARING AGENCY: Savannah District	

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
B. J. Halliburton	January 1970	Comp.	Op.

A. PURPOSE OF PROGRAM

The program determines the stability of an overflow monolith at the plane of the base and at any horizontal plane up to and including the plane where the pier toe intersects the curve of the weir. It computes the stability of a weir only, an ungated spillway with piers for bridge support, and a gated spillway. It also computes the stability for the construction condition, the normal operating condition, the induced surcharge condition, the flood discharge condition and a maintenance condition all simultaneous or either one or ones desired.

B. PROGRAM SPECIFICATIONS

FORTRAN

C. METHODS

The method of analysis and solution generally follows the outline given in EM 1110-2-2200, Gravity Dam Design.

D. EQUIPMENT DETAILS

GE-225 8K, card reader, card punch,
900LPM printer and 4 magnetic tapes.

E. INPUT-OUTPUT

F. ADDITIONAL REMARKS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Gravity Dam, Pier & Spillway Analysis	713-R3-C1-090

PREPARING AGENCY
Kansas City District

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Marion Harter, Melvin Javett, Byron Bircher, Roy Reed			Op.

A. PURPOSE OF PROGRAM

The program determines the overturning and sliding stability of any gravity overfall spillway structure that has either a horizontal or an irregular base.

B. PROGRAM SPECIFICATIONS

FORTRAN using the RCA 305 compiler

C. METHODS

The program first calculates both the dead load forces of the structure (pier and overfall) and the water load forces acting on the structure. Using these combined forces, the program then determines the overturning and sliding stability of the structure.

D. EQUIPMENT DETAILS

RCA 301 Central Processor with 40K memory
RCA 330 Card Reader
RCA 381 Magnetic tape unit
RCA 333 Printer

E. INPUT-OUTPUT

F. ADDITIONAL REMARKS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Spillway and Pier Monolith Stability Analysis			713-R3-A3-150
PREPARING AGENCY: St. Louis District			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Kenneth R. Kollar Joe Davis			

A. PURPOSE OF PROGRAM

Analysis of a spillway (with ogee wier) and pier monolith. The analysis may be applied to a spillway monolith alone or a spillway monolith with pier, at the users option.

B. PROGRAM SPECIFICATIONS

Card - FORTRAN

C. METHODS

The program computes the dead load and dead moment (about the heel) of the spillway and pier from their respective geometrys. It analyzes the spillway for overturning and sliding stability with the following conditions: (a) construction condition w & w/o earthquake. (b) normal operating conditions w & w/o earthquake. (c) induced surcharge condition (d) flood discharge condition.

D. EQUIPMENT DETAILS

Originally written for RCA 301
Converted to Honeywell G-400 Batch

E. INPUT - OUTPUT

F. ADDITIONAL REMARKS

Documentation is available from St. Louis District.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Stability Analysis - Overflow Gravity Dam	713-F5-D0-105

PREPARING AGENCY

New England Division

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Paul R. Laliberte	June 1972		

A. PURPOSE OF PROGRAM

The program investigates stability of an ogee-spillway section. As options, the program will increase the upstream slope or the depth of key in order to meet existing criteria. As a result, the most economical section may be found with a minimum of effort. Base pressures are found.

B. PROGRAM SPECIFICATIONS

Any ogee weir section may be analyzed with the added option of a bucket downstream. The program also has provisions for a gated spillway, a gallery and various projections on the upstream side. Uplift reduction and passive pressure can be used.

C. METHODS

Conventional engineering techniques are used. The program has been prepared in accordance with criteria as set forth in EM 1110-2-2200 and ETL 1110-2-63. Standard programming methods in FORTRAN IV are used.

D. EQUIPMENT DETAILS

The program is written for a GE 427 (64K) computer and requires 5,598 words of memory in its present form.

Components include an on-line card reader and printer and an off-line card punch.

E. INPUT-OUTPUT

Input is on punched cards and consists of a project title card, a station and case card, and pertinent data cards. Any number of stations and/or cases may be investigated. Output provides listing of descriptive data for the section analyzed.

F. ADDITIONAL REMARKS

The program has been successfully used for design of Trumbull Dam and Bloomington Dam.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Overflow Stability Analysis			13-G1-M005
PREPARING AGENCY			
Tulsa District			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Dean B. Englund	October 1968	Init.	Op.

A. PURPOSE OF PROGRAM

This program computes the uplift pressures, the horizontal thrust, the crest pressure, the bucket forces, the resistances to sliding and the base pressures for a controlled or uncontrolled ogee weir monolith.

B. PROGRAM SPECIFICATIONS

The program is written in CARD FORTRAN.

C. METHODS

The method of computation follows the criteria set forth in EM-1110-2-2400, "Structural Design of Spillways and Outlet Works" dated Nov. 2, 1964 and EM-1110-2-2200, "Gravity Dam Design"

D. EQUIPMENT DETAILS

The equipment required is the GE 225 central processor (8K memory) with a card reader, a magnetic tape subsystems with 2 tape handlers and a high-speed printer.

E. INPUT – OUTPUT

Input is by cards.

Output is on printer paper.

F. ADDITIONAL REMARKS

None

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Lock Wall Stability - One Foot Section			722-S8-K5-180
PREPARING AGENCY			
Mobile District - Corps of Engineers			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Charles W. Kling	March 1974	Comp.	Op.

A. PURPOSE OF PROGRAM

This program will provide the user with a complete stability investigation of a one foot section of a lock wall. The design option compares the normal conditions (lower pool in the lock and upper pool in the lock) and determines the most economical section based upon the stability requirement of the resultant falling within the beam as required by EM 1110-2-2602. In addition, the program will provide printed output far any loading condition, showing the resultant on the base, base and foundation pressures and shear-friction safety factor.

B. PROGRAM SPECIFICATIONS

The program was written and compiled in Univac FORTRAN IV language, however, care was taken not to use any features of the language that would prevent the program from compiling on any FORTRAN IV compiler. The object program requires 8552 36-bit words for executions.

C. METHODS

The program computes forces and moments, assumes 2 uplifts, has a strut reaction option, vertical and horizontal forces are summarized and contains a shear-friction safety factor.

D. EQUIPMENT DETAILS

Univac 1108

Card reader and printer

E. INPUT – OUTPUT

Input – Card

Output – Printer

F. ADDITIONAL REMARKS

Documentation is available from Mobile District.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Lock Wall Stability Analysis - Investigation			13-K2-H403
PREPARING AGENCY			
Pittsburgh District			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
W. R. Noullet L. R. Hoy	November 1967		

A. PURPOSE OF PROGRAM

The purpose of this program is to determine lock wall base pressures, stability against overturning and sliding, and percent of active base for loading conditions as specified in EM 1110-2-2602.

B. PROGRAM SPECIFICATIONS

This program is written in FORTRAN IV using floating point arithmetic. The object program requires 14,547 bytes of main storage in addition to the supervisor

C. METHODS

Forces and moments are computed on the basis of lock wall configuration, foundation material, and pool and earth elevations at lock wall faces. Unit active earth pressures for dry and saturated earth and water are incorporated in the program. At-rest, surcharge and sloping fill earth pressures, miter gate and service bridge loads and forces are added as external loads.

D. EQUIPMENT DETAILS

This program is presently being processed on an IBM 360/30, e3K system using the 2501 card reader and the 1443 printer.

E. INPUT - OUTPUT

Input for the program is via the 2501 card reader. Output is via the 1443 printer

F. ADDITIONAL REMARKS

FORTRAN coding, card format, sample input-output, and object decks are available.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Lockwall Analysis			713-F5-F2-014
PREPARING AGENCY			
Chicago District			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
John . D'Aniello	June 1970	Comp.	Op.

A. PURPOSE OF PROGRAM

The program analyzes a gravity-type wall founded on rock and of a cross section that can be described by the variables. Results of the analysis include the safety factor against sliding, safety factor in bearing and the location of the resultant from the toe of the wall.

B. PROGRAM SPECIFICATIONS

FORTRAN IV

C. METHODS

The program analyzes the stability of a lockwall for loading conditions specified in EM 1110-2-2602, Planning and Design of Navigation Lockwalls and Appurtenances, by applying the equilibrium conditions. Forces that maybe considered are hydrostatic force on the lockside face, hydrostatic and silt or soil forces on the riverward or landward wall, anyone of three different uplift criteria and, if desired, earthquake forces. Other forces acting on the structure, such as hawser, ice, wind, and impact loads may be considered, but must be input directly as concentrated forces.

The maximum bearing pressure, factor of safety in bearing, factor of safety against sliding, and the location of the resultant force are determined and printed as output.

D. EQUIPMENT DETAILS

E. INPUT-OUTPUT

F. ADDITIONAL REMARKS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
River and Middle Wall Stability Analysis	713-21-011

PREPARING AGENCY

Huntington District - Nashville District modified program # NS-02-1300

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Structural Section	October 1961		Oper.

A. PURPOSE OF PROGRAM

Selects base width for foundation pressure and stability for lock wall analysis. The wall will have foundation pressures and sliding factors within specified limits. The resultants can be selected to be within the one-third or one-fourth point for each load case.

B. PROGRAM SPECIFICATIONS

FORTRAN IV using floating point arithmetic

C. METHODS

The base width is proportioned such that the controlling will be within their respective criteria limits by 0.55 ft. An iterative solution is used to adjust base width.

D. EQUIPMENT DETAILS

GE-200, card reader and printer

E. INPUT-OUTPUT

Input - punched cards

Output - Printer

F. ADDITIONAL REMARKS

Sample input, output, and writeup available.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Land Wall Stability Analysis	713-F7-R4-030 (713-24-030)

PREPARING AGENCY

Huntington District - Nashville District modified program # NS-03-1300

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
William E. Galyean			Dev.

A. PURPOSE OF PROGRAM

Selects base width, heel and toe dimensions of land lockwalls for foundation pressure, stability and sliding criteria.

B. PROGRAM SPECIFICATIONS

FORTRAN IV using floating point arithmetic.

C. METHODS

An iterative solution is used to adjust base dimensions. This version considers arching active and at-rest earth pressures, shears-friction sliding and earthquake criteria.

D. EQUIPMENT DETAILS

GE-635, Timesharing terminal.

E. INPUT-OUTPUT

Input - Data file

Output - Printed, labeled and ready for filing.

F. ADDITIONAL REMARKS

Upon completion this program will be converted for use on batch equipment.

The earlier version of this program (713-21-013) is now obsolete.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Gravity Dam Stability Analysis			713-K5-G1-040
PREPARING AGENCY			
Alaska District			
AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
John Penzien	October 1968		Op.

A. PURPOSE OF PROGRAM

This program uses the Finite Nodal Point Method for gravity dam stability analysis and can be used for design of any gravity dam non-overflow and spillway sections. The programs also provides analysis for sloped bases, iterate for full uplift, should tension exist at the heel, and analyze a section with two different materials; for example, a concrete dam resting on granite with analysis required on planes projecting through the granite. Changes in spillway parabala curve equations may require revision depending on hydraulic preferences.

B. PROGRAM SPECIFICATIONS

FORTRAN IV (120)

C. METHODS

Accuracy depends on the population of nodal points since the trapezoidal rule was used for generating the volume and center of gravity (section one foot long).

D. EQUIPMENT DETAILS

IBM System 360/50 with 512K core storage.

E. INPUT-OUTPUT

Input - Card

Output - Printer

F. ADDITIONAL REMARKS

Documentation is available.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
Two-Dimensional Stability Analysis	713-K5-G4-440

PREPARING AGENCY

Walla Walla District

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
James E. Krussel	July 1969		Op.

A. PURPOSE OF PROGRAM

This program provides a means for analyzing a monolith with or without applied loads for stability in two dimensions. The monolith itself is broken up into sections; these sections are defined three dimensionally and must satisfy specified input requirements. External loading can be defined three dimensionally (as with a pressure diagram) along with a unit weight of material, or by point loads with the corrdinates of the point of application. Seismic forces can be applied to the monolith in either the vertical or horizontal direction and will act through the center of gravity of the monolith.
The program will compute the summation of forces in the vertical and horizontal directions, all base properties including base pressure at desired points, factors of safety, volume and centroid of monolith, and coordinates of the resultant.

B. PROGRAM SPECIFICATIONS

FORTRAN IV (120)

C. METHODS

D. EQUIPMENT DETAILS

IBM OS 360/50 with 512K storage, direct access, magnetic tapes, card read/punch w/on-line printer.

E. INPUT-OUTPUT

F. ADDITIONAL REMARKS

Documentation is available.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM Stress Analysis - Nonoverflow Gravity Dam	**PROGRAM NO.** 713-F5-D0-101
PREPARING AGENCY New England Division	
AUTHOR(S) Paul R. Laliberte	**DATE PROGRAM COMPLETED** August 1971
STATUS OF PROGRAM	**PHASE** / **STAGE**

A. PURPOSE OF PROGRAM

The program computes end stress at any specified elevation within a nonoverflow concrete gravity dam section. Stresses are also computed at the ends of an opening (i.e. gallery) if located at the elevation specified. Vertical and inclined compressive stress and shear stress are given as output.

B. PROGRAM SPECIFICATIONS

Pertinent data entered for the station includes the elevation at which computed stresses are desired. Force and stress computations are made for each elevation and followed by output of results.

C. METHODS

Conventional engineering techniques are used. The program has been prepared in accordance with criteria as set forth in EM 1110-2-2200 and ETL 1110-2-63.

Standard programming methods in FORTRAN IV are used.

D. EQUIPMENT DETAILS

The program is written for a FE 427 (64K) computer and requires 6,024 words of memory in its present form.

Components include an on-line card reader and printer and an off-line card punch.

E. INPUT-OUTPUT

Input is on punches cards and consists of a project title card, a station and case card, and pertinent data cards. Output provides a listing of descriptive data for the sections analyzed.

F. ADDITIONAL REMARKS

The program has been successfully used for design of Trumbull Dam.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM Powerhouse Stability Analysis	PROGRAM NO. 713-K5-CO-010
PREPARING AGENCY North Pacific Division	

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM PHASE	STAGE
R. L. Willey	June 1968	ORGIN	

A. PURPOSE OF PROGRAM

To analyze the loads acting on a powerhouse for evaluation of its stability. Program furnishes the values of all loads and their moments about the x and y axes. Loads and moments are summarized into values parallel to the axes. Loads and moments are divided into structural, applied, and earthquake. The program determines the location of the resultant at Base Plane Elevation, total values of loads parallel to the three axes and the total value of moments about the x-x and y-y axes.

B. PROGRAM SPECIFICATIONS

Program is codes in FORTRAN IV language. The following axis position is assumed: x-x axis horizontal and parallel to the longitudinal axis of the powerhouse; y-y axis horizontal and normal to x-x axis; z-z axis, vertical. Input values are restricted to certain horizontal and vertical loads imposed on a powerhouse structure, lever arms and dimensions describing various volume shapes plus earthquake data and are expressed in kips and in feet.

C. METHODS

Standard arithmetic means are used in calculating volumes, moments and loads defined by the card types containing required parameters. As each load, volume and moments are calculated these are printed and summaries are performed until all data has been processed. At this time a summary sheet is printed containing all summarized results and moments plus the location of the resultant force.

D. EQUIPMENT DETAILS

Computer: IBM System/360
Operating System: IBM System/360 Operating System
Core Requirements: (Excluding Operating System 28K bytes
Secondard Storage: None

E. INPUT-OUTPUT

All input is from punches cards conforming to a fixed format depending on the card type. In many cases, several of a given type may be used and cards may be in any order that the last card must be blank to initiate the summary sheet.

F. ADDITIONAL REMARKS

This program has not been documented although card input formats are available as are sample jobs. The program was conceived and written for a specific job and may not be applicable for others to use effectively.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Finite Element (Equilibrium Model) Plane Stress/Strain			713-K5-G3-480

PREPARING AGENCY

Seattle District

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
George W. Ploudre	Aug 1971	Comp	Op.

A. PURPOSE OF PROGRAM

This program offers an accurate solution to the plane problem without any restrictions as to the shape of the plate, or on the boundary conditions. Normal shear stresses are computed for each element of the analysis. This program and its finite element model were developed by Dr. Vernon Watwood and Dr. Richard Schwaegler of the Civil Engineering Department of Seattle University.

B. PROGRAM SPECIFICATIONS

FORTRAN

C. METHODS

The finite element method of analysis is employed within this program uses an "equilibrium" model rather than the more common "displacement" model. In this approach, an equilibrium stress field is chosen within each element, and by matching surface traction vectors between elements, the stress field is made continuous from element to element. Since the stresses are the primary unknown with this model, their accuracy is better than if determined by an equivalent "displacement" model.

D. EQUIPMENT DETAILS

IBM System 360 Model 50 Operating System.

E. INPUT-OUTPUT

F. ADDITIONAL REMARKS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM			PROGRAM NO.
Finite Element Method Stress Analysis			713-K5-G4-710
PREPARING AGENCY			
Walla Walla District			
AUTHOR(S)	**DATE PROGRAM COMPLETED**	**STATUS OF PROGRAM** PHASE	STAGE
Dr. Clough & Dr. Wilson, Univ. of CA, Berkeley, Mod. by G. L. Anderson	April 29, 1968	Mod.	Rep.

A. PURPOSE OF PROGRAM

The purpose of this program is to provide a means of determining displacement and stresses within a plane solid with either linear or bi-linear material properties. The analysis, which is general, can be applied to any shape of structure. Loading may be any combination of node forces, displacements, or temperatures.

B. PROGRAM SPECIFICATIONS

The program is written in FORTRAN IV and requires double-precision on the IBM 360 system. Program capacity is 1700 nodes, 1700 elements and a maximum band of 45. Run time is 25 minutes for a mesh size of 1200 nodes and 1200 elements.

C. METHODS

Program uses the Finite Element technique where the structure is described by a quadrilateral mesh composed of elements which are interconnected at the nodes. From input describing nodes, elements, and material properties, the total structural stiffness is formulated. Using the stiffness and applied loads the node displacements are computed. These are then used to determine the stress in each element.

D. EQUIPMENT DETAILS

The program requires an IBM 360 Model 50 System with 2 tape units, disc storage, card reader and on-line printer. The program requires 307,000 Bytes of core. Two disc files of 2,462,400 Bytes each and one disc file of 116,000 Bytes external storage are required.

E. INPUT - OUTPUT

Input is X and Y coordinates of each node, nodes describing each element, and properties of each material in the structure.

Output consists of node displacements and stress at center of each element. Output stresses are X-stress, Y-stress, shear stress, principal stresses and angle of orientation.

F. ADDITIONAL REMARKS

Optional output on magnetic tape provides a plot tape which, when plotted on a Benson-Lehner Model LTE Plotter, gives quadrilateral layout, displaced structure and vector plots to aid interpretation of results.

Also, optionally provided is a magnetic tape which is used as input to a contouring program.

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
SAP4-Structural Analysis Program	713-F3-R0-012

PREPARING AGENCY

Automatic Data Processing Center, Waterways Experiment Station

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
K. Bathe, E. Wilson, F. Peterson, Univ. Calif. Berkeley, California	June 1973	Complete	Final

A. PURPOSE OF PROGRAM

SAP4 was designed to be an effective and efficient computer program for analyzing very large complex 3-D structural systems; however, there is no loss in efficiency in the solution of small problems. Nine structural element types may be used in a static or dynamic analysis. In a dynamic analysis the options are: (1) frequency calculation; (2) frequency calculation followed by response time history analysis; (3) frequency calculation followed by response spectrum analysis; (4) response time history analysis by direct intergration.

B. PROGRAM SPECIFICATIONS

Batch FORTRAN IV. (Array A is 8000) single precision.

C. METHODS

Finite element merhod structural analysis.

D. EQUIPMENT DETAILS

Honeywell G-635, 54K (36-bit word) memory, card reader, printer, disc or tape for temporary storage.

E. INPUT-OUTPUT

Input - Nodal point data may be in cartesian (x,y,z) or cylindrical (r,z,θ) coordinates. Boundary conditions are defined for each node. Element data include material properties such as Young's Modulus, Poisson's ratio and weight density. Nodal and element loads may be input. Dynamic input includes ground acceleration, time-varying loads and damping coefficient.

Output - Static output is nodal displacement and translation. (Continued) Element output includes axial stress and force, shear moment, stress and torque. Cynamic output is structural modes and frequencies (eigenvalue/eigenvector) with selected nodal displacement and element stress components.

F. ADDITIONAL REMARKS

Report available: "A Structural Analysis Program for Static and Dynamic Response of Linear Systems" - K. Bathe, E. Wilson, F. Peterson. EERC 73-11 June 1973: University of California, Berkeley, California

Contact: W. L. Boyt (WES) 601 636-3111 (FTS 542-3507) ADPC

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
ICES - STRUDL - II	802-K5-G0-800

PREPARING AGENCY

North Pacific Division

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
M.I.T. Civil Engineering Systems Laboratory			

A. PURPOSE OF PROGRAM

This program performs static and dynamic analysis for 2-D and 3-D structural systems. It also has member selection capabilities.

B. PROGRAM SPECIFICATIONS

Batch ICETRAN (ICES, FORTRAN), FORTRAN II, FORTRAN IV, ASSEMBLER

C. METHODS

Finite Element approach to structural analysis.

D. EQUIPMENT DETAILS

IBM 360/50, 230K (32-Bit-word) memory, card reader, printer, Disc direct-access storage.

E. INPUT-OUTPUT

Card Input, Printer Output

F. ADDITIONAL REMARKS

Reports Available - "ICES STRUDL - II Engineering User's Manual"
Vol 1 "Frame Analysis" R68-91
Vol 2 "Additional Design & Analysis Facilities R68-92
Vol 3 "Reinforced Concrete Structures" R68-93

U-FRAME LOCKS: ANALYSIS AND DESIGN STATE OF THE CORPS ART

by

Charles Hargett*

Foreword

The information contained herein was obtained from a variety of publications and miscellaneous papers and from the author's first-hand experience in developing design procedures and analysis techniques for Felsenthal and Calion Locks and Dams on the Ouachita River Navigation Project in Arkansas. The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the Vicksburg District nor of the Corps of Engineers. It is hoped that this summary of the State of the Corps Art for U-frame lock design and analysis will be beneficial, not only to the research engineer, but most especially to the practicing engineer.

Acknowledgements

Since this report is intended to summarize the research efforts and experience in the design and analysis of U-frame locks, it is impossible to mention all of those persons and agencies whose experience and knowledge has been included herein.

The author gratefully acknowledges the assistance of Dr. N. Radhakrishnan and Mr. Wayne Jones, both of the Waterways Experiment Station (WES), with whom the author worked closely during the past several years, especially during the analysis of Calion Lock. Sincere thanks and personal appreciation are extended to Messrs. Vic Agostinelli, Lower Mississippi Valley Division (LMVD), and Curtis Sewell, Vicksburg District (VXD), whose diligent efforts, patience, and practical experience have contributed considerably to the development of analysis and design procedures which may soon make the use of the finite element U-frame code a practical design tool for the practicing engineer.

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* Structural Engineer, Vicksburg District, Lower Mississippi Valley Division.

PART I: INTRODUCTION

Navigation locks are used to enhance a river's navigation capabilities by decreasing river gradients and increasing water depths. A hydraulic profile of the Ouachita River Navigation Project showing the location of four such locks, with corresponding decreases in gradients and increases in depths, is shown in Figure 1. (The two uppermost locks, Felsenthal and Calion, will be constructed as U-frame locks.) A typical lock configuration indicating the approach monoliths, upstream and downstream gate bay monoliths, and chamber monoliths is shown in Figure 2. Several different lock chamber sections, including gravity monoliths and U-frame monoliths, are shown in Figure 3. Because of the simplicity of design and construction, the gravity type monoliths, either soil or pile founded, have received widespread acceptance in the United States; the U-frame, because it allows greater diversity in design and placement, has been used extensively on the inland waterways of Europe.

Both monolith types, or a combination of the two types on the same lock, such as U-frames for gate bay monoliths and gravity walls for chamber monoliths, have been used successfully by the Corps of Engineers. Both configurations have their applications.

The lack of acceptance for U-frames in the United States can be attributed to the uncertainties in estimating the magnitude and distribution of external loading conditions and resulting pressures.

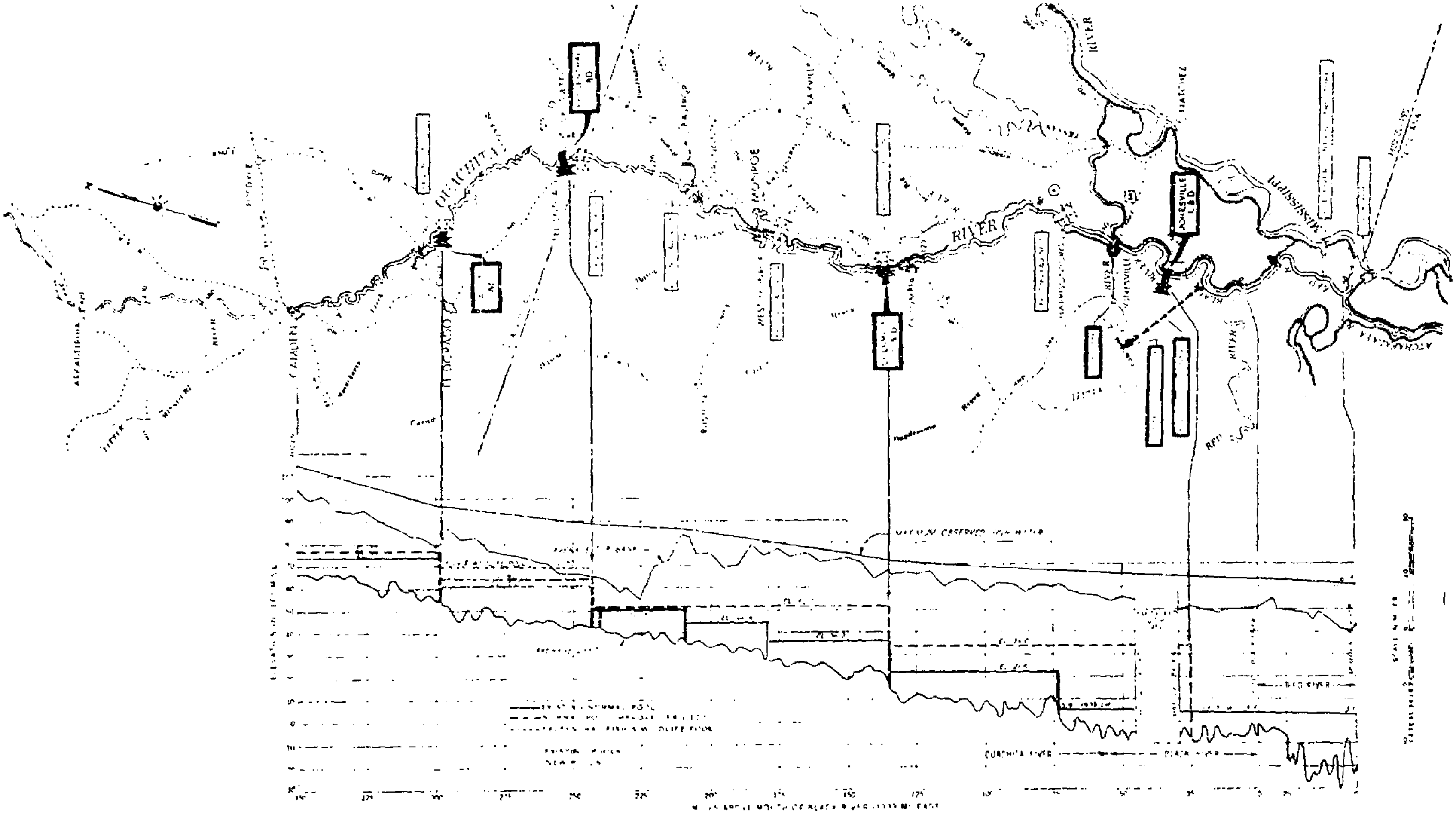


Figure 1. Hydraulic profile of Ouachita River navigation project

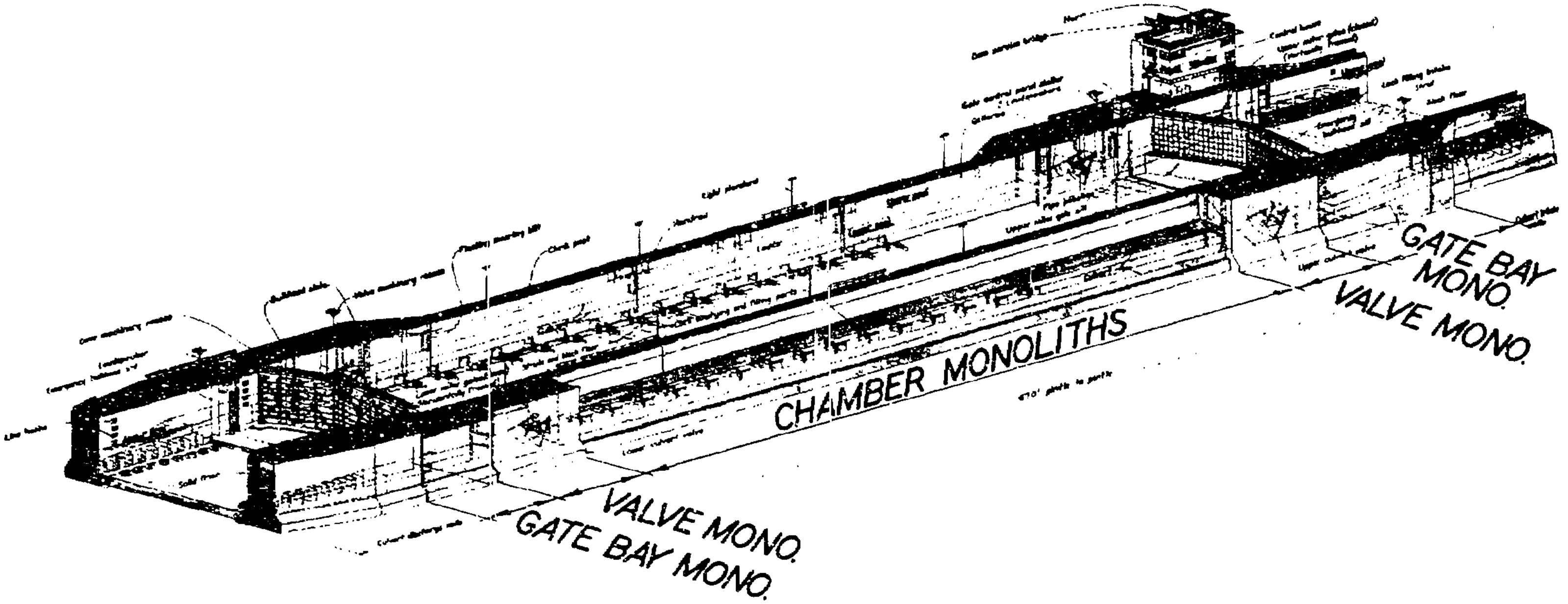


Figure 2. Isometric of typical lock

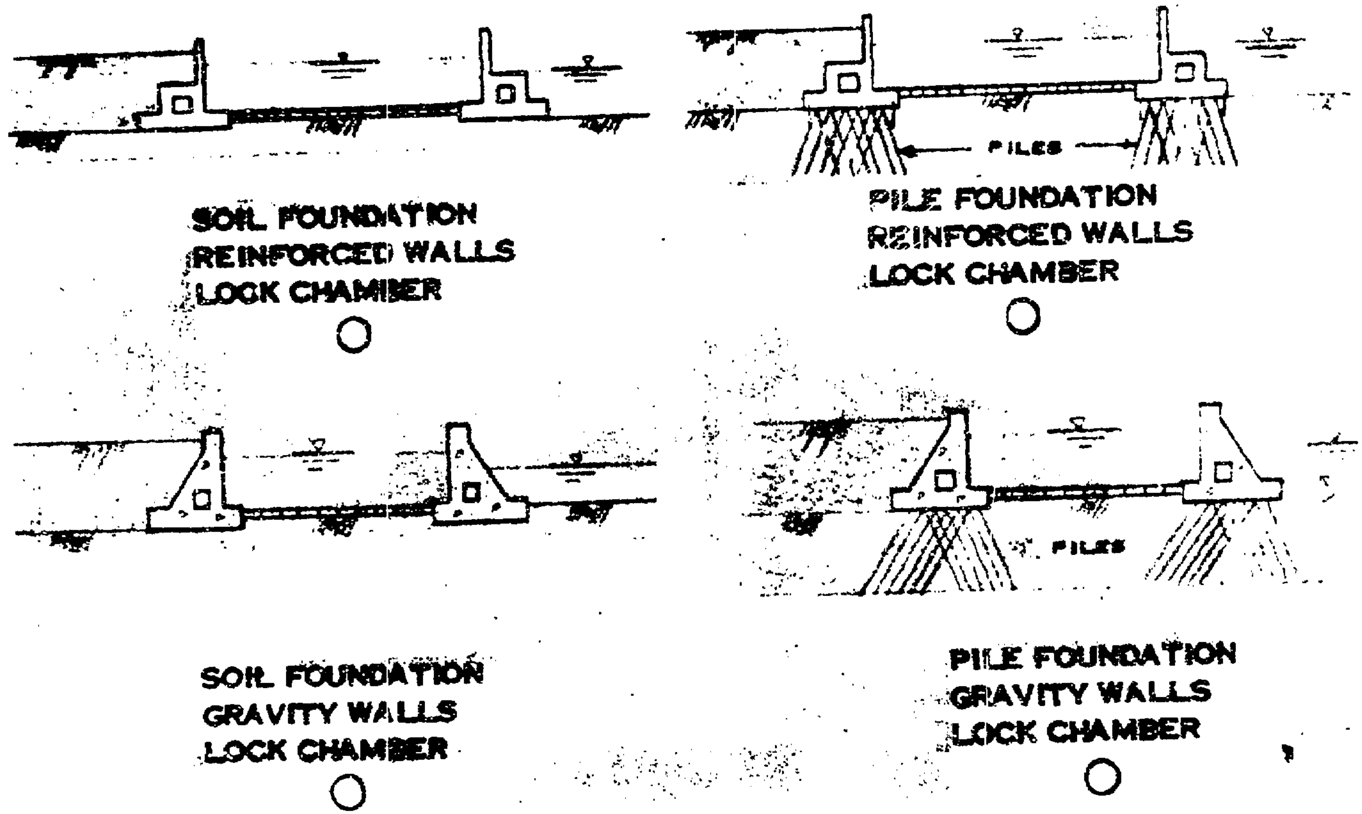


Figure 3. Lock chamber sections (sheet 1 of 2)

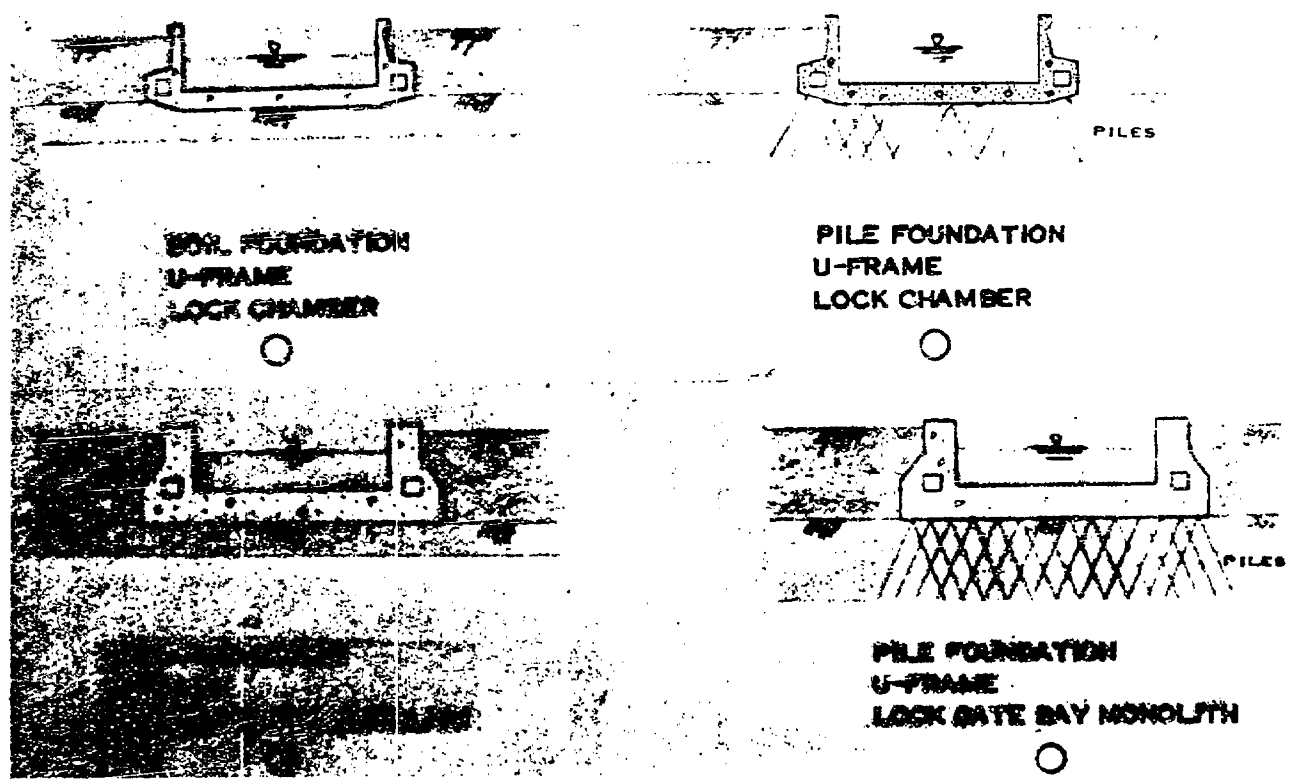


Figure 3 (sheet 2 of 2)

PART II: SELECTION OF U-FRAME LOCK MONOLITHS

General

Poor foundation conditions, requiring costly pile foundations for gravity monoliths, can often be eliminated by the use of the U-frame. U-frame monoliths can normally be founded directly on the subsoil without the use of piles or special foundation treatment and without the use of elaborate drainage systems, even though the subsoil may be very compressible.

Chamber Monoliths

Gravity type lock-chamber monoliths are normally constructed with an articulated concrete-block floor in the lock chamber. (See Figure 4.) Such an arrangement, although simple to construct, normally requires an elaborate unwatering system when inspection and maintenance of the lock walls, floor, and filling and emptying conduits and ports are required. The U-frame chamber can be unwatered safely at any time, with more favorable distribution of loads and with a minimum number of dewatering wells.

Gate Bay Monoliths

One of the obvious advantages of the U-frame is its use as a gate bay monolith. For gate bays with miter type gates attached to the lock walls, and with the walls and the gate sill constructed as independent monoliths, only a slight differential settlement or tilt can cause gate leakage, improper sealing, gate vibrations, and gate distortions. The U-frame gate bay, with the walls and gate sill acting as a unit, eliminates differential settlements and undesirable tilts and the possibility of gate damage. Gate bay monoliths, because of their size, shape, and weight, may still require a pile foundation; but the distortion problem can and should be eliminated by using U-frames for the gate bays. (See Figure 4A.)

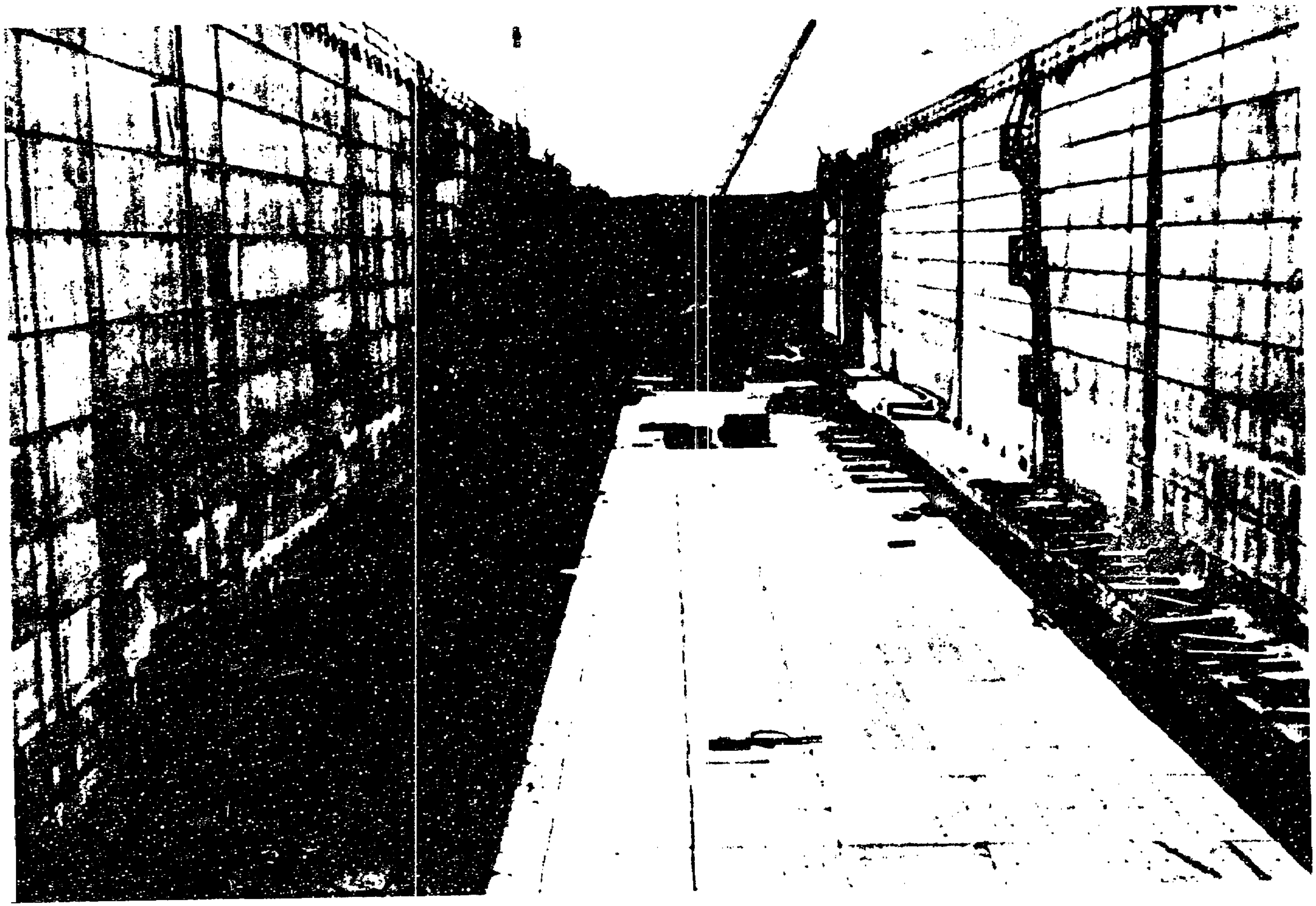


Figure 4. Lock-chamber floor blocks

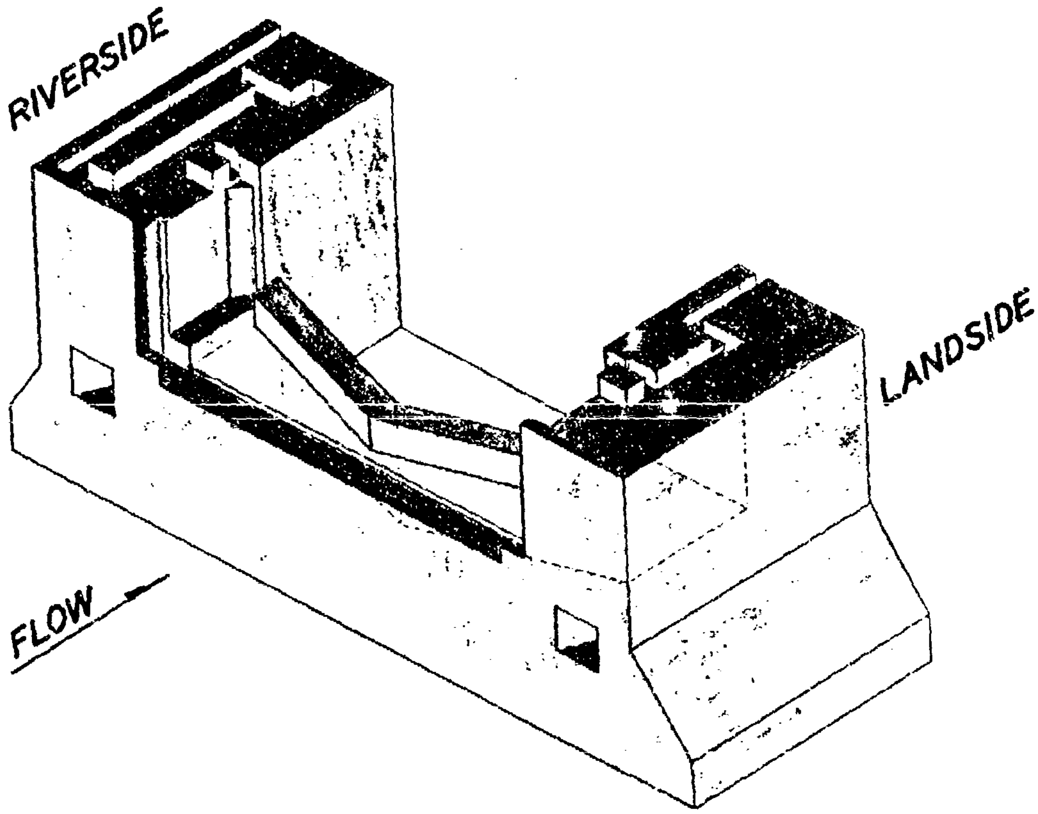


Figure 4A. Gate bay monolith isometric view

PART III: METHODS OF ANALYSIS

General

In an attempt to gather instrumentation data which could be used in the design of U-frame locks, the Mississippi River Commission (MRC) designed, constructed, and instrumented two U-frame locks: Port Allen Lock, located on the Gulf Intracoastal Waterway near Port Allen, Louisiana, completed in 1961; and Old River Lock, located at the mouth of the Red River near its juncture with the Mississippi, completed in 1963. Aerial views of Port Allen and Old River are shown in Figures 5 and 6, respectively. Most of the available current design data are based on the analysis of the instrumentation data collected from these locks.[1,2]

Loading Conditions

The primary forces acting on a U-frame lock are shown in Figure 7. The base pressures oppose the downward load of the lock, which consists of the weight of lock W_C and the weight of the water inside the lock W_W, the weight of the backfill above the culverts W_B, and the vertical component of the lateral earth pressures E_V. The downward thrust W is resisted by the uplift forces u and effective foundation base pressures P.

The magnitude of the uplift pressures depends on the upstream and downstream water elevations, the character of the foundation strata, and the nature and effectiveness of measures installed to control uplift pressures. Uplift pressures generally vary significantly along the length of the lock.

The distribution of the effective base pressures is dependent upon complex interactions between the soil and structural elements of the lock and is the major unknown factor in design. The lateral pressures exerted on the lock walls include the water pressure E_W in the backfill and in the lock and the effective horizontal earth pressures E_H. These pressures are dependent on the type of backfill material

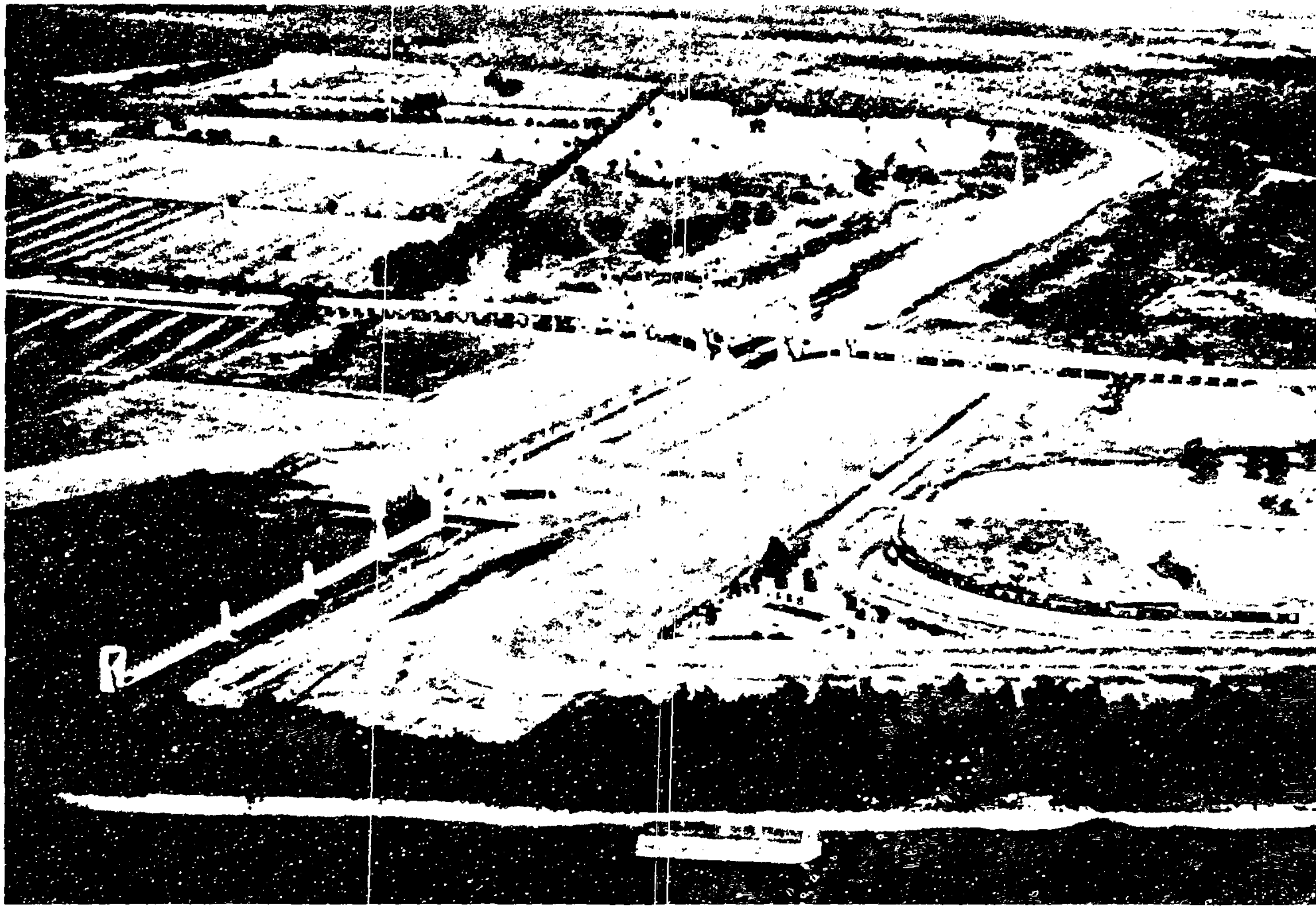


Figure 5. Aerial view of Port Allen Lock

Figure 6. Aerial view of Old River Lock

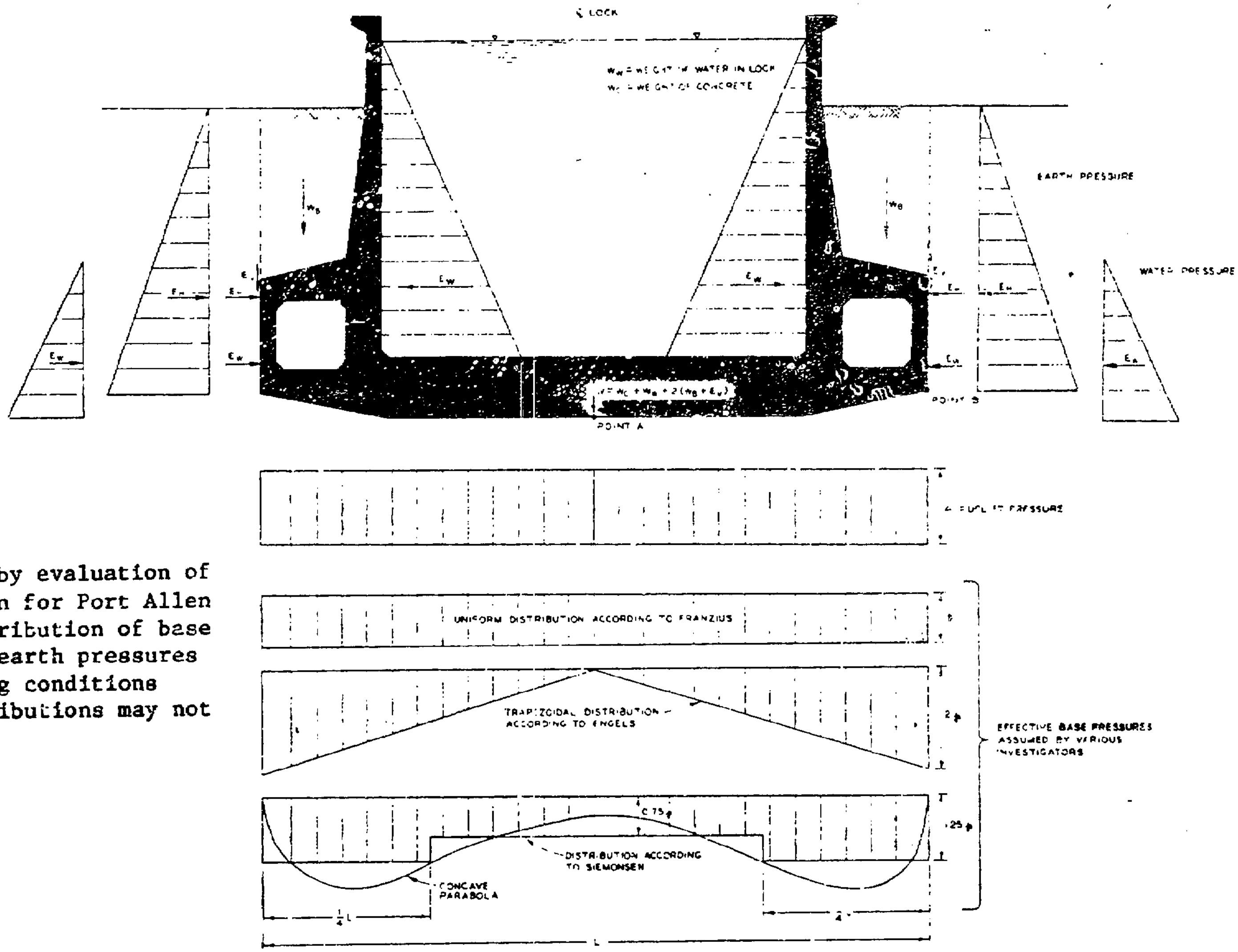
and its in-place characteristics and are also a function of wall movement.

Consequently, the principal elements of design for a U-frame section consist of insuring the safety of the chamber sections against uplift, determining stresses occurring at the center of the base slab and at its juncture with the chamber walls, analyzing the culvert frame, if used, and analyzing the stability of the side walls.

The design is always based on two principal loading conditions: (a) lock empty and (b) lock full. Other loading conditions (i.e., lock complete with no backfill placed, and lock partially filled), frequently critical, may develop during and after construction. These must also be considered in design.

The most important elements in the design of a U-frame structure are the assumptions regarding the pressure distributions at the base of the lock and the magnitude and distribution of lateral earth pressures, including vertical components. In the case of relatively rigid base slabs, it is common practice to assume a base pressure distribution, independent of the possible deformations, and to compute the resulting bending moments on the basis of this assumed base pressure distribution. Most early lock construction used relatively rigid base slabs. The following three different assumptions regarding the distribution of base pressures have been commonly used for both the "lock full" and the "lock empty" conditions: (a) a uniform pressure distribution, (b) a trapezoidal or double triangular pressure distribution, and (c) a concave parabolic pressure distribution, often idealized by rectangular base pressures under the slab and walls.

In none of the above distributions were the relations between the structural deflections of the floor slab and the deflections of the subsoil taken into consideration. These distributions are shown in Figure 7.[1] (Note: As shown by the evaluation of instrumentation for Port Allen,[2] the distribution of lateral earth pressures may not be triangular, as shown in Figure 7. The base pressure distributions may not be applicable for relatively flexible U-frames, such as Port Allen and Old River.)



NOTE: As shown by evaluation of instrumentation for Port Allen Lock, the distribution of base pressures and earth pressures vary as loading conditions change. Distributions may not be as shown.

Figure 7. Force system on lock and assumed base pressure distribution

Methods of Analysis

Essentially three methods of analysis have been used in the design of U-frame lock monoliths: (a) beam on elastic foundation, (b) conventional elastic frame analysis, and (c) the finite element method. Each of these methods and their applicability will be briefly discussed in the following paragraphs.

Beam on elastic foundation

For U-frame structures with relatively flexible base slabs, various assumptions have been introduced concerning the distribution of the base pressure; however, it has been generally accepted that the most satisfactory method for analyzing such structures is by the theory of elastic beams on a continuous elastic support. This theory is based on the fact that the vertical deformation of the base slab must at every point be equal to the settlement of the underlying foundation soils at the same point. Consideration is given to the fact that the vertical deformation of the slab at a given point depends not only upon the intensity of load at this point but also upon the adjacent stresses and thus upon the entire base pressure distribution.

The ratio between the intensity of load on the foundation and the corresponding settlement is designated as the coefficient of subgrade reaction. Difficulties associated with the determination of reliable values of the coefficient of subgrade reaction have been thoroughly discussed in various technical papers.[2]

In determining the effective foundation base pressures for the design of Port Allen Lock, it was considered that available design procedures using the theory of beams on elastic foundations would not be a logical approach to the problem, as they neglected foundation rebound and the effects of backfill placement. Furthermore, the foundation conditions were relatively complex, and important time effects were anticipated. Analysis of the instrumentation data proved these assumptions to be correct. Base pressure distribution and bending moments using the theory of beams on elastic foundations differed significantly from those observed at Port Allen Lock. (See Figure 8.)

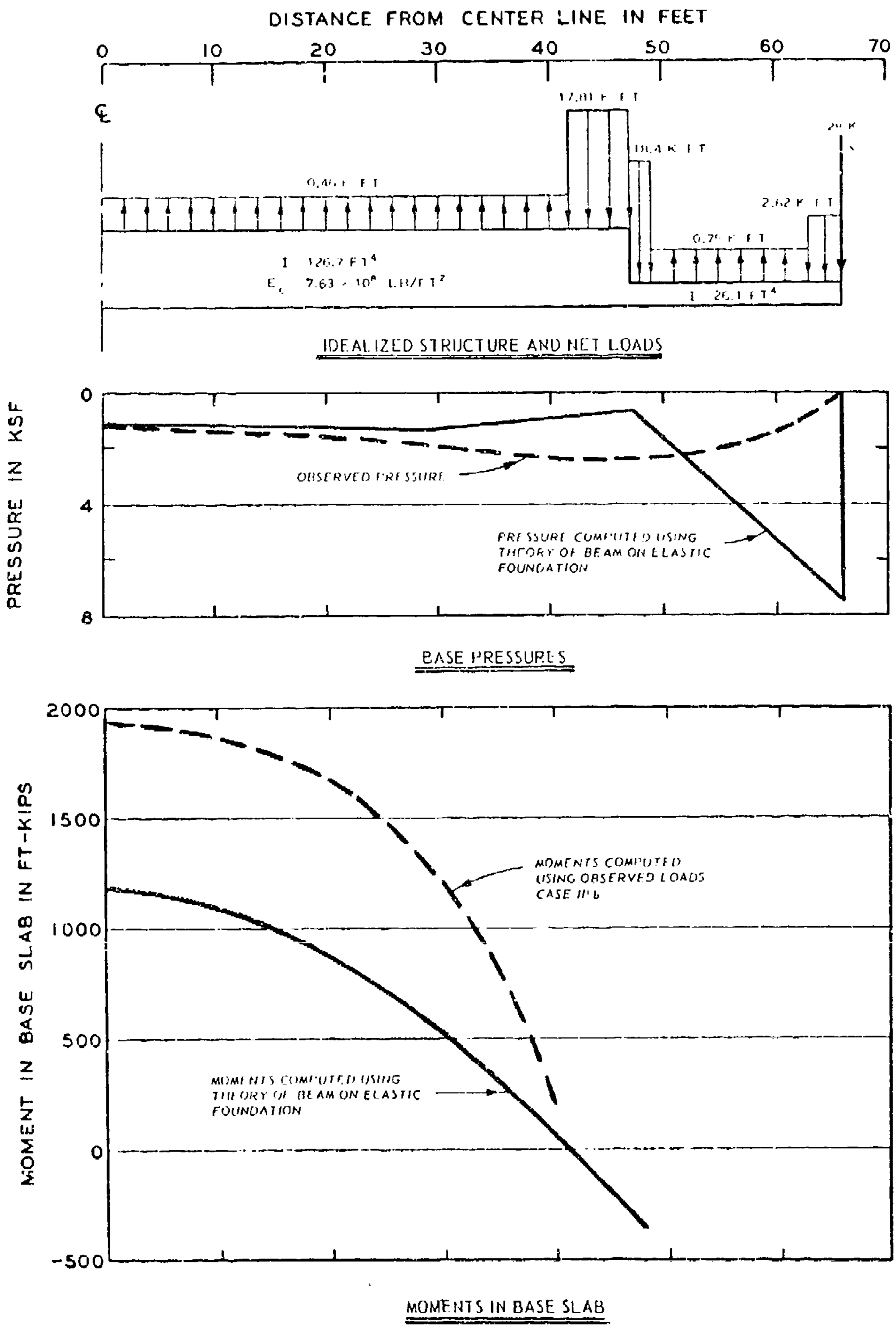


Figure 8. Base pressures and moments based on theory of beam on elastic foundation

Conventional methods

Conventional analysis based on slope deflection, moment distribution, or similar elastic-frame theory has been applied successfully in preliminarily sizing members for use in more sophisticated analysis such as the finite element method. Currently, the most popular conventional analysis seems to be the slope-deflection computer program as developed and published by Dr. Fred Beaufait et al., Vanderbilt University, under the auspices of "Computer and Matrix Methods of Structural Analysis."[3] Dr. Beaufait's program has received widespread application within the Corps under such titles as "G-Frame,"[4] "O-Frame,"[5] or "Non-Orthogonal Plane Frame Analysis."[6] This program, because of its input simplicity and wide range of loading conditions reduces the laborious task of sizing the U-frame culvert members, wall stem, and base slab. Another similar program based on moment distribution is entitled "A Computer Program for Lock Culvert Frame Analysis."[7]

Any conventional analysis, however mathematically correct, is dependent upon the external loads and pressure distributions. Even though such distributions were recommended from the evaluation of instrumentation data for Port Allen and Old River Locks, their applicability is limited to future locks with similar width-to-depth ratios, similar flexibility, and similar soil conditions. From the results of the instrumentation at Port Allen (see Figure 9), it was concluded that the distribution curve of effective base pressures beneath the lock is in the general shape of a concave parabola with the maximum pressures occurring about 40 to 50 ft from the center line of the lock. (Inside lock chamber width and lock wall height for Port Allen are 84 ft and 68 ft, respectively.) Even though the base pressure distribution observed is a concave parabola, a uniform base pressure may be assumed for preliminary design purposes. Cognizance must also be taken of the frictional (drag) forces that might develop along the sides of the lock during various stages of construction. Distribution of lateral earth pressures for the various loading conditions can be obtained from Reference 1.

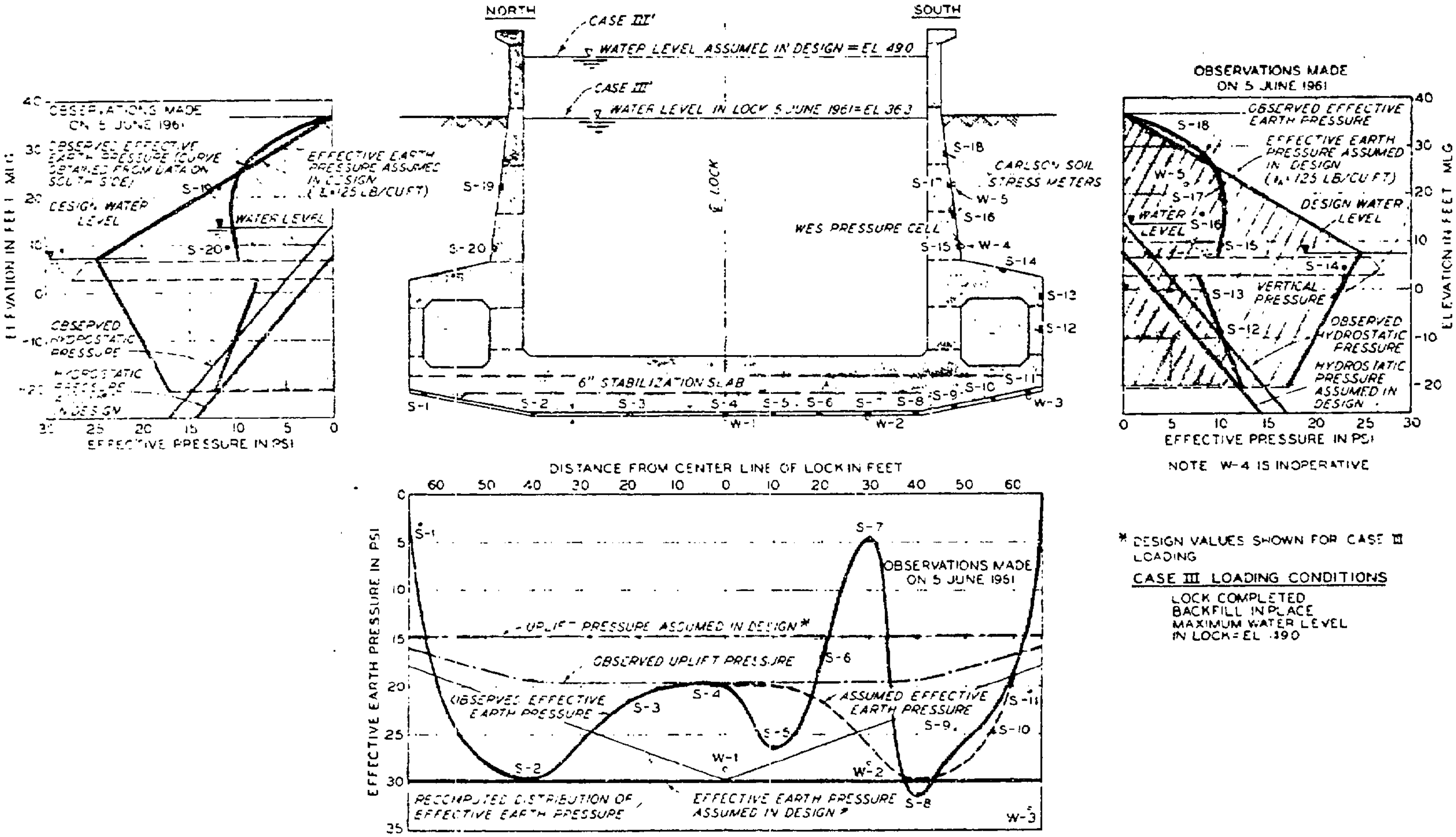


Figure 9. Port Allen Lock instrumentation results - effective earth pressures

Finite element method

Since neither the beam on elastic foundation nor the conventional methods mentioned above considers the total soil structure interaction, neither is a totally acceptable design procedure. The finite element method shows promise because of its diversity in materials and because incremental procedures can be considered to idealize actual construction sequences such as dewatering, stages of excavation, stages of placing concrete, stages of backfilling, changes in pore pressures, changes in temperature, and changes in external loads. This approach as applied to the analysis of a typical lock-chamber monolith (1-ft strip) was developed by Drs. Clough and Duncan in September 1969.[8] Gate bay monoliths, whose configurations require a three-dimensional monolithic analysis, are not within the present capabilities of existing U-frame finite element codes.

Analysis advantages. By using an incremental analysis, a more realistic representation of the stress-strain behavior of the backfill and foundation soils can be obtained. This type of analysis has the advantage of considering the total soil-structure interaction, such as (a) excavation rebounds, (b) structure and backfill settlements, (c) structural deflections, (d) earth pressures, (e) downdrag on lockwalls, (f) moments, shears, and thrusts in lock members, and (g) the effects of seasonal temperature variations. In addition, this analysis can also consider other loads, such as impact, hawser pull, surcharge, unwatering, and earthquake.

Shortcomings. Attempts to apply the original finite element U-frame code to the analysis of Calion Lock revealed several undue restrictions. (The use of the original U-frame code should be approached with caution.) Several of these restrictions have been properly documented, and the original code has been modified to correct these deficiencies.* Even with these modifications, however, the user should be aware of several input restrictions, which, if unheeded, can be catastrophic in both time and money:

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* N. Radhakrishnan and H. W. Jones, "User Guide for Modified U-Frame," U. S. Army Engineer Waterways Experiment Station, CE, report to be published.

a. An adequate number of soil borings should be made in the area to be investigated to determine the stratification and extent of in situ soil properties. The soil borings are important since they are a source from which soil samples are obtained. (Care should be used to obtain undisturbed samples.) Tests are run on these soil samples to obtain the soil parameters necesary for calculating the required soil material input parameters for the program. Soil parameters can be determined from triaxial or plane strain compression tests. However, if these tests are not available, it is possible to determine the required soil parameters from results of the direct shear and one-dimensional consolidation tests. A computer program has been written to compute the soil material input from the results of the consolidation and direct shear test.*

b. The input for the structural material (concrete) can be prepared by following the procedures recommended by the American Concrete Institute (ACI) Committee Report (1966) on deflections in structural members. On Port Allen and Old River Locks the cross section was used for all the structural components of the lock and a sustained modulus was used to account for long term deflections. This assumption is partially correct, but it does not consider the effects of cracking patterns which do occur in flexural reinforced-concrete members. The validity of the results obtained when the effects of cracking are neglected is questionable. A more thorough discussion can be found in the paragraph on the effects of structural cracking below.

c. The design of the finite element mesh should be given careful thought and planning before it is drawn. When designing the mesh, the following factors will influence the mesh configuration:

(1) The initial geometry of the in-place soil and the final geometry of the structure.

(2) Increments of excavation, concrete placement, and backfill placement. Initially, the incremental analysis for Calion Lock was set up to dewater, excavate in four steps, place concrete in five steps, and backfill in four steps. The computer output indicated poor results using this setup. It was found that soil elements were failing and results of output between successive iterations on some elements were not in good agreement, even though the increments of excavation were well within the guidelines presented on page 72 of Reference 8. It was decided to try smaller increments of excavation, concrete placement, and backfilling. On runs using the smaller excavation

* H. W. Jones, "Soils Parameters for U-Frame FEM," U. S. Army Engineer Waterways Experiment Station, CE, unpublished computer routine.

increments, the results between successive iterations on each increment did improve, but isolated elements were still not in good agreement between successive runs. Caution should be exercised to ascertain that increments of excavation, concrete placement, and backfilling are small enough to give reliable results.

(3) Location of excavation and backfill slopes.

(4) The location of each soil stratification.

(5) The use of symmetry, if possible.

(6) Location of lateral boundaries.

(7) The number of elements required to appropriately represent the lock structure so as to obtain satisfactory values of deflections, moments, and shears. This restriction is discussed further in the paragraphs on mesh refinement and mesh generating routine below.

(8) Interface elements.

(9) The restrictions on the number of elements, nodal points, and maximum numerical difference of nodal point numbers within any one element.

(10) Use of quadrilateral shaped elements.

It should also be noted that design of the mesh should involve a joint effort between soils and structural engineers to achieve the optimum mesh design.

Effects of Structural Cracking

As indicated in the paragraphs on loading conditions, the base pressure distributions and lateral earth pressure distributions, and their magnitudes, are dependent on a complex soil-structure interaction whereby the distributions and magnitudes are dependent on the rigidity (or flexibility) of the U-frame members. Any finite element analysis, wherein the mesh configuration and materials properties neglect the effects of cracking in reinforced concrete, by assuming continuous elastic or inelastic elements and a simplified sustained modulus, can be grossly in error. The results obtained from such analysis will be based on a structural flexibility that is not idealized properly, and whose computed displacements and stresses are significantly incorrect. If universally acceptable results are to be obtained, the flexibility

of the structure must be idealized. The effects of neglecting cracking must not be minimized.

The effects of the cracking of reinforced-concrete members and of creep and shrinkage on long-term deflections have been the subject of intensive research for the past two decades; an elaborate discussion of these effects in this paper is not warranted. A brief discussion of the behavior of a typical reinforced concrete is presented below.

When the load on a reinforced concrete member is gradually increased from zero to that magnitude which will cause the beam to fail, several different stages of behavior can be clearly distinguished. At low loads, as long as the maximum tension stress in the concrete is smaller than the modulus of rupture, the entire concrete is effective in resisting stress in compression on one side and in tension on the other side of the neutral axis (elastic analysis). In addition, the reinforcement deforms the same amount as the adjacent concrete and is also subject to tension stresses. At this stage all stresses in the concrete are of small magnitude and are linearly proportional to strains. A frontal and a cross-sectional view of a reinforced-concrete beam along with the distribution of strains and stresses in concrete and steel over the depth of the section is as shown in Figures 10a, 10b, and 10c.

When the load is further increased, the tension strength of the concrete is reached, and tension cracks develop. These propagate upward movement with progressive cracking. The general shape and distribution of these tension cracks is shown in Figure 10d. The presence of cracks affects profoundly the behavior of the beam under load. In a cracked section, i.e., in a cross section located at a crack, the concrete does not transmit any tension stresses; it is the steel which resists the entire tension. However, it is appropriate to note that concrete fails to resist any tension stresses only where a crack is located. Between cracks, the concrete resists moderate amounts of tension stress; with corresponding reduction in tension stress in the steel. At moderate loads (concrete stresses not exceeding approximately fc'/2*),

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation, p 77.

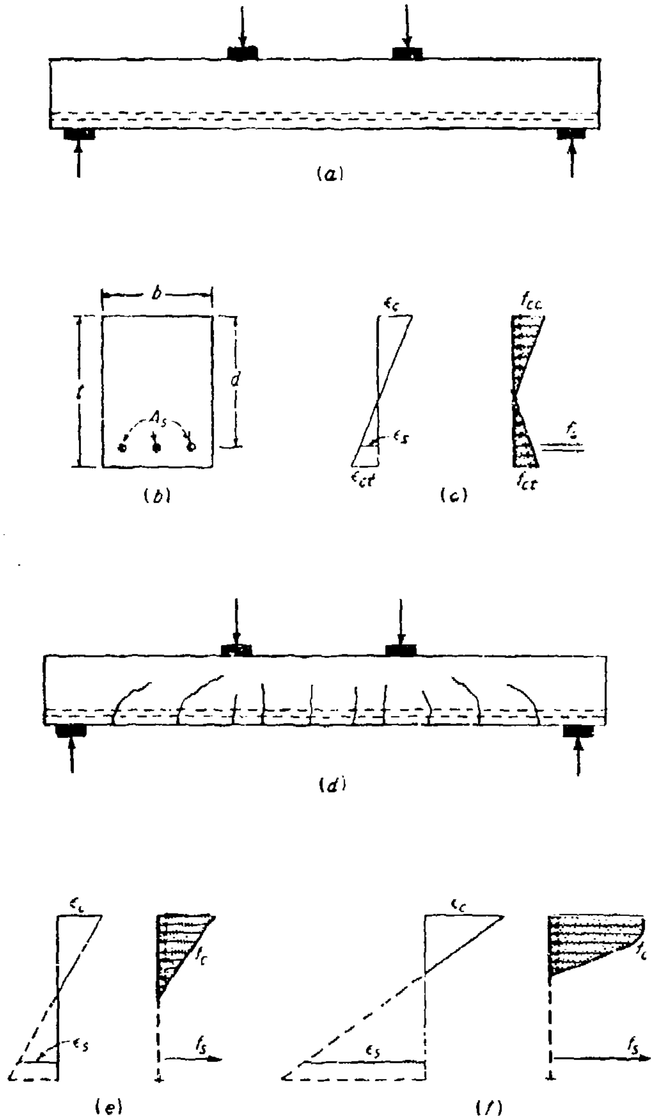

Figure 10. Behavior of reinforced-concrete beam under increasing load

stresses and strains continue to be approximately proportional. The distribution of stresses and strains at or near a cracked section is then shown in Figure 10e. When the load is still further increased, stresses and strains rise correspondingly and are no longer linearly proportional. The nonlinear relation between stresses and strains is that given by the concrete stress-strain curve (see Figure 10f). Therefore, the distribution of concrete stresses on the compression side of the beam is of the same shape as the stress-strain curve.

Eventually, as loads are increased, the carrying capacity of the beam is reached, and the beam fails. When relatively moderate amounts of reinforcement are employed (as is the case for properly designed beams), the steel will reach its yield point; the reinforcement yields somewhat suddenly and elongates a large amount. The tension cracks in the concrete widen visibly and propagate upward; the deflection of the beam increases significantly. When this happens, the strains in the remaining compression zone of the concrete increase until crushing of the concrete occurs at a load only slightly larger than that which initially caused the steel to yield. Such yield failure is gradual and is accompanied by visible signs of distress, such as the widening and lengthening of cracks and the marked increase in deflection.

In addition to those concrete deformations which occur immediately upon load application, as in the above discussion, there are other deformations and volume changes which take place gradually and over long intervals of time. Deflections of reinforced-concrete members continue to increase for some time after load application, at a decreasing rate, and the longtime deflections may exceed the instantaneous deflections by a large amount. Longtime deflections are caused by shrinkage and by creep (chiefly by the latter). Creep deformations of concrete are directly proportional to the compression stress. They increase asymptotically with time and, for the same stress, are larger for low-strength concretes than for high-strength concretes. Correspondingly, longtime deflections caused by sustained loads on cracked reinforced-concrete sections can be as much as twice as large or larger than those for the same load assuming an uncracked elastic section.

Cracking of the Floor Slab at Port Allen Lock

The Port Allen Lock Chamber was unwatered for a periodic inspection in February 1972. A close examination of the floor slab, while unwatered, showed numerous hairline cracks, whose pattern and spacing were similar to those caused by a combination of flexural cracking and temperature changes. (The pattern and crack spacing for Monolith 15 are shown in Figures 11 and 12.) This cracking may have been suspected in advance of the unwatering since the stresses, for several case loadings, as obtained from instrumentation placed in this monolith, were in excess of those necessary to cause cracking. The effects of cracking should not be neglected in any analysis, even when the results of the finite element analysis based on nonlinear, elastic, or inelastic proportions may seem to yield reasonable results. As long as the basic idealized mechanism is in error, any method of analysis, whereby the validity of the assumptions can be changed or verified by in-hand instrumentation readings, will never receive universal acceptance as a design and/or analysis tool for future structures.

Summary of Deflection Criteria

It is sufficient to say that determination of realistic deflections of cracked reinforced members is dependent upon an elaborate interaction between two dissimilar materials. No method whereby this interaction is simplified, even those elastic deflection methods presented in the ACI code 318-71, will yield displacements of the accuracy necessary to provide reasonable results in the finite element analysis. The finite element code must be capable of idealizing the state of stress in each concrete element and thereby determining the effective moment of inertia which will allow for a gradual transition from uncracked to cracked section.

Finite Element Mesh

Mesh refinement

In order to obtain realistic displacements and internal stresses

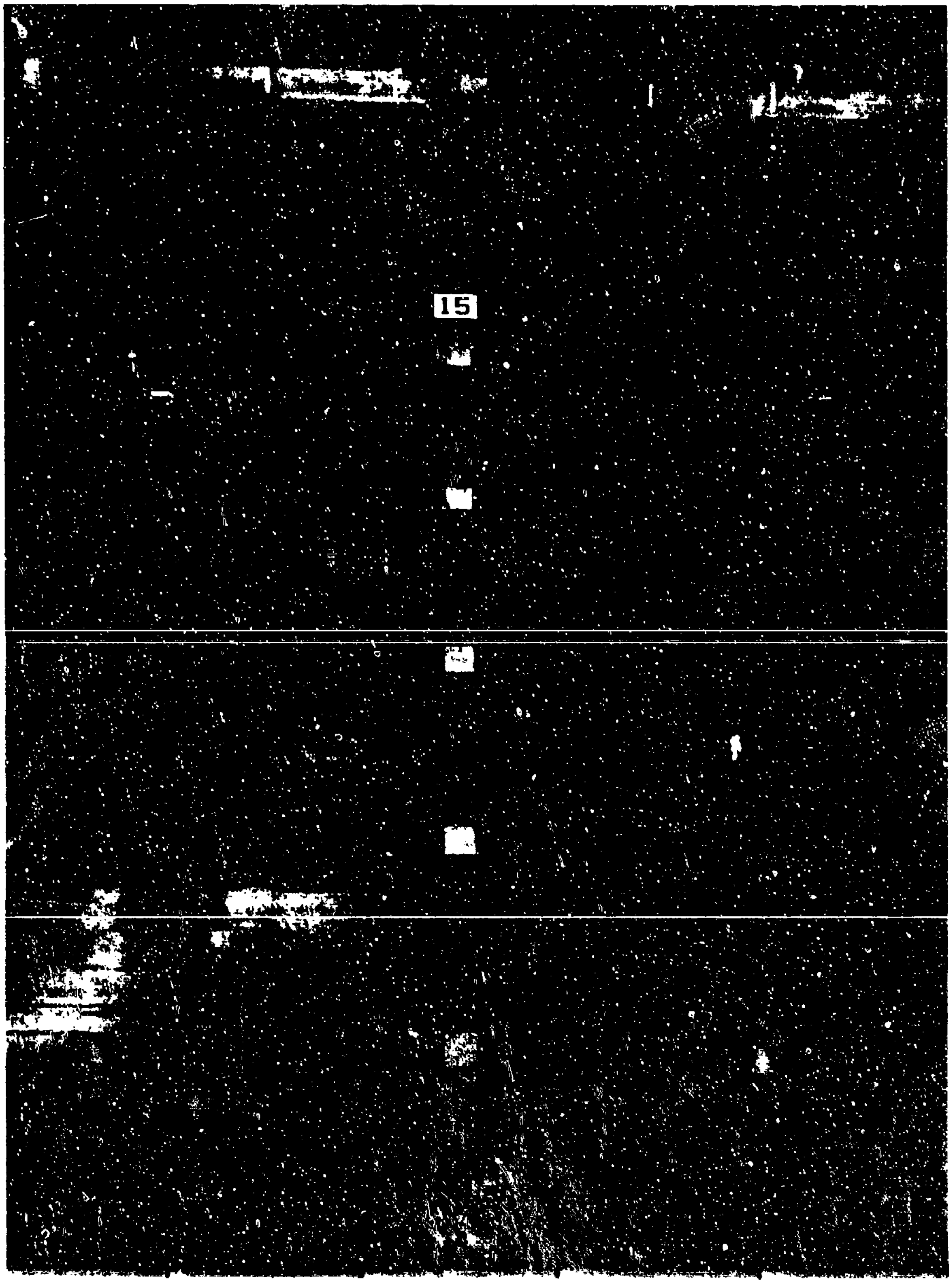

Figure 11. Cracks in floor slab at Port Allen Lock, north wall

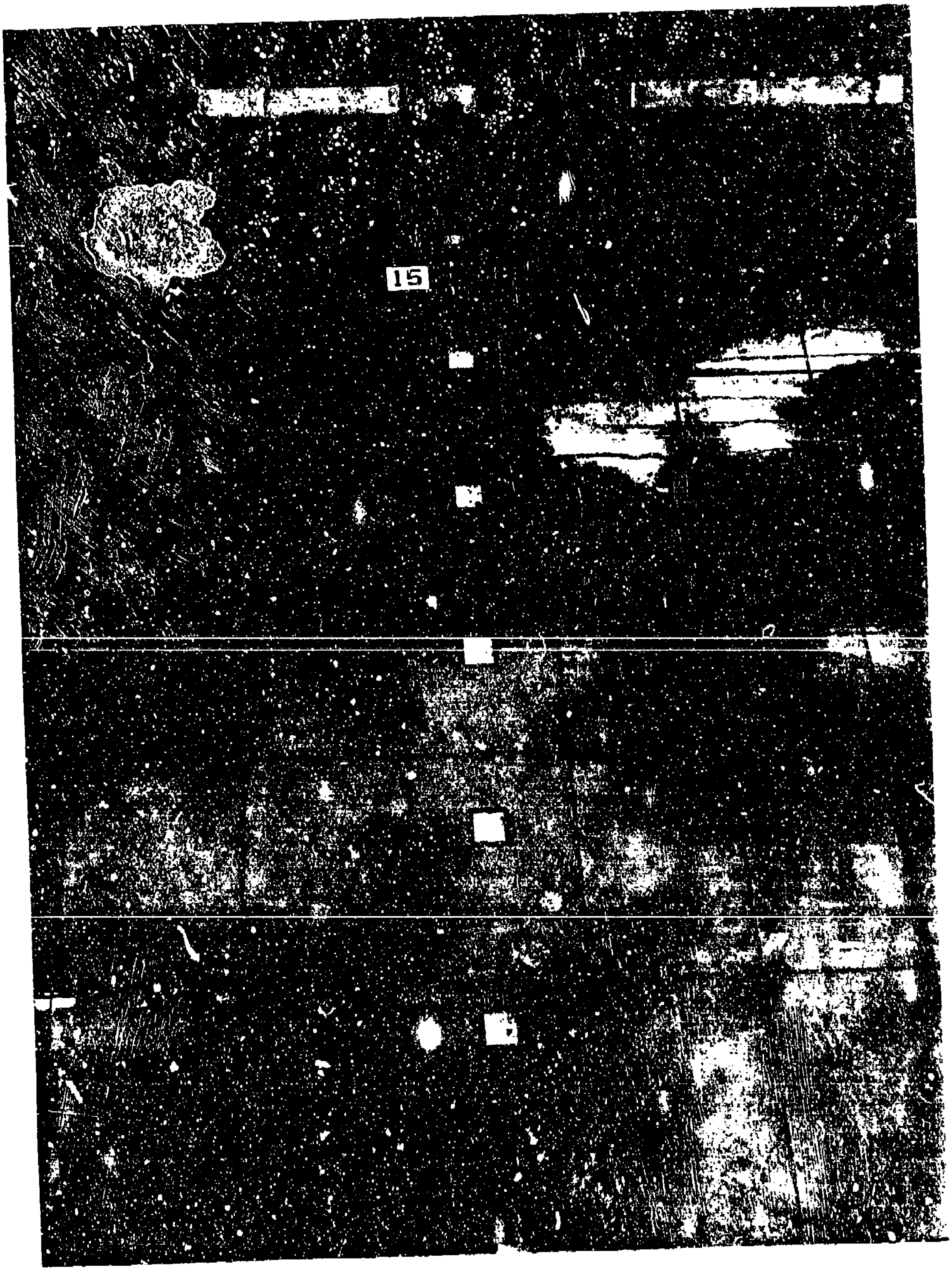

Figure 12. Cracks in floor slab at Port Allen Lock, south wall

from a finite element U-frame analysis, the mesh must be refined so that element size and geometry depict the actual flexibility of the structure and provide for the correct soil-structure interaction. In other words it must be determined, "How finite is finite?" Even with the more refined elements, such as the isoparametric quadrilateral element used by Dr. Radhakrishnan and Wayne Jones,* the mesh reinfinement is critical, even when the analysis considers concrete as a purely elastic material. The refinement becomes even more critical if the stresses are to be used to calculate moments, shears and axial forces. There must be an adequate number of elements to provide enough stress points to calculate these vectors. During the process of calculating moments and axial forces from internal stresses for the Calion Lock, it was determined that the original mesh design for the structure was not refined enough to give realistic moments for design. Parametric studies were conducted on the wall stem, considering it to be a cantilevered beam, and on the base slab, considering it to be a simply supported beam. The results of the parametric studies for the moments are shown in Figure 13. Good correlation was obtained for the axial load in the stem even with a relatively coarse mesh, therefore only the mesh refinement for moments is presented here. It may be noted that the number of elements across the member and the number of elements along the member are of almost equal importance. In other words, for best results, the length and width of the elements should be approximately equal. The isoparametric quadrilateral element was used in the parameter study.

Mesh generating routine

The Computer Analysis Branch (CAB) of the Waterways Experiment Station (WES) realized that the finite element method could never receive widespread acceptance as a design tool unless the tedious, laborious, mesh input preparation could be greatly simplified. An interactive graphics finite element mesh generating routine has been written by Mr. F. T. Tracy and is presently operational on a limited basis. Briefly, this routine requires the user to define only the

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* Radhakrishnan and Jones, op. cit.

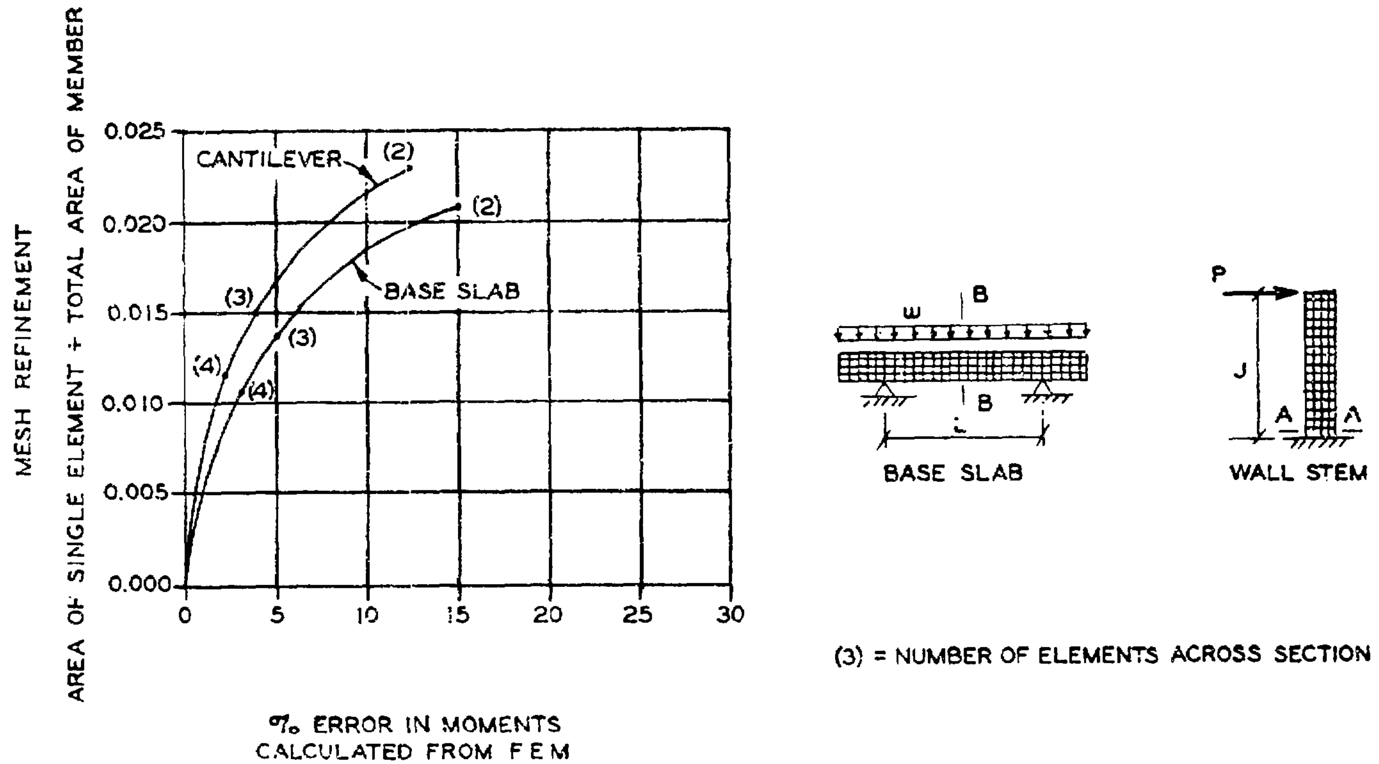

Figure 13. Error percentage in moments calculated from FEM

boundary or boundaries and to specify the number of incremental divisions along each boundary. The routine breaks the areas within the boundary limits into finite elements (quadrilateral or triangular, user option), then generates the grid, numbers the nodes and elements, and prepares the necessary grid input for use with the U-frame code. This technique greatly reduces the effort required to revise or refine a finite element grid, and greatly enhances the finite element method's potential as a design tool.

PART IV: AVAILABLE COMPUTER PROGRAMS

General

Although there are several programs bearing titles such as U-frame or lock analysis, essentially, only three such programs yield reasonable results; even then the user must be aware of the limitations and shortcomings of such programs as previously discussed. The programs which the author believes to be useful in the design and analysis of U-frame lock-chamber monoliths are listed below. These programs are for two-dimensional analysis only, and none are capable of analyzing three-dimensional gate bay monoliths or monoliths with culvert filling and emptying ports.

Conventional Method

"A Computer Program for Lock Culvert Frame Analysis"; P. K. Senter and F. T. Tracy, WES Miscellaneous Paper K-73-5, June 1973. This report describes and presents instructions for using a computer program which calculates the shears and moments of the frame encompassing the side culvert in a lock wall. The program allows the design engineer to determine shears and moments at the selected locations on the structure for any desired loading conditions, and thus to design the structure based on a comprehensive study of the system and at an economical cost. The program assumes a U-frame lock with predetermined symmetric loading (equal loads on each side of the lock). The lock culvert is treated as being composed of four members which act as a frame. Any of the individual members may have a varying depth along its length.

The moment-distribution method of frame analysis is used in this program. This method is a standard frame analysis method for frames which are composed of members with a large span/depth ratio. It should be noted that as the span/depth ratio becomes small, the moment-distribution method gives less accurate results. Shear deformation must then be taken into account or the finite element method must be used

to obtain more accurate results. The general shape of a cross section of the lock-chamber wall and culvert is presented in Figure 14. Two options are available for the general shape of both the upper wall geometry and the lower wall geometry as shown by the solid (Option 1) and dashed (Option 2) lines. Four factors are considered in the computations: normal loading on the frame, external loading on the frame, horizontal sidesway, and vertical sidesway. The geometry and a typical loading case are shown in Figure 15. This program is especially valuable in determining preliminary member sizes for use in more sophisticated analysis such as the finite element U-frame code.

Finite Element Programs

There are two finite element codes available for analysis of U-frame lock-chamber monolith.

Original U-Frame

"Finite Element Analysis of Port Allen and Old River Locks," G. W. Clough and J. M. Duncan, WES Contract Report S-69-6, Sep 1969. This code has numerous limitations and shortcomings (as discussed in the paragraph Shortcomings and the section Effects of Structural Cracking in Part III above) and should be used with caution.

U-Frame Modification

"User Manual for Modified Program U-Frame," N. Radhakrishnan and H. W. Jones, WES, CAB (to be published). This code modifies the original U-frame code and many of the limitations and shortcomings experienced in the original code have been eliminated. It also includes provisions for axially loaded piles. This code should be used with caution and then only with an awareness of the costs involved in gridding, preparing input, and running costs.

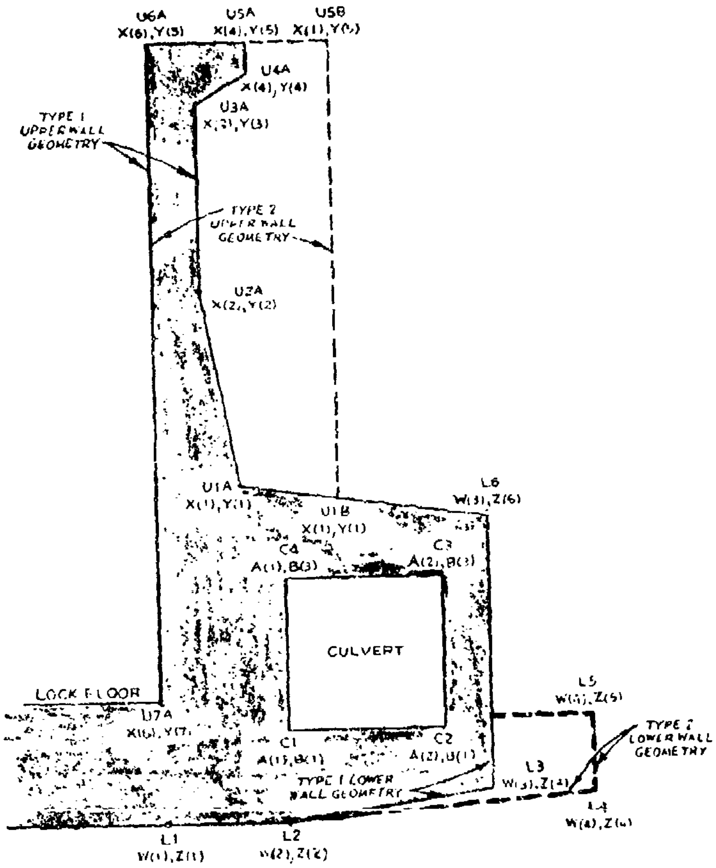

Figure 14. Conventional analysis - required geometry input

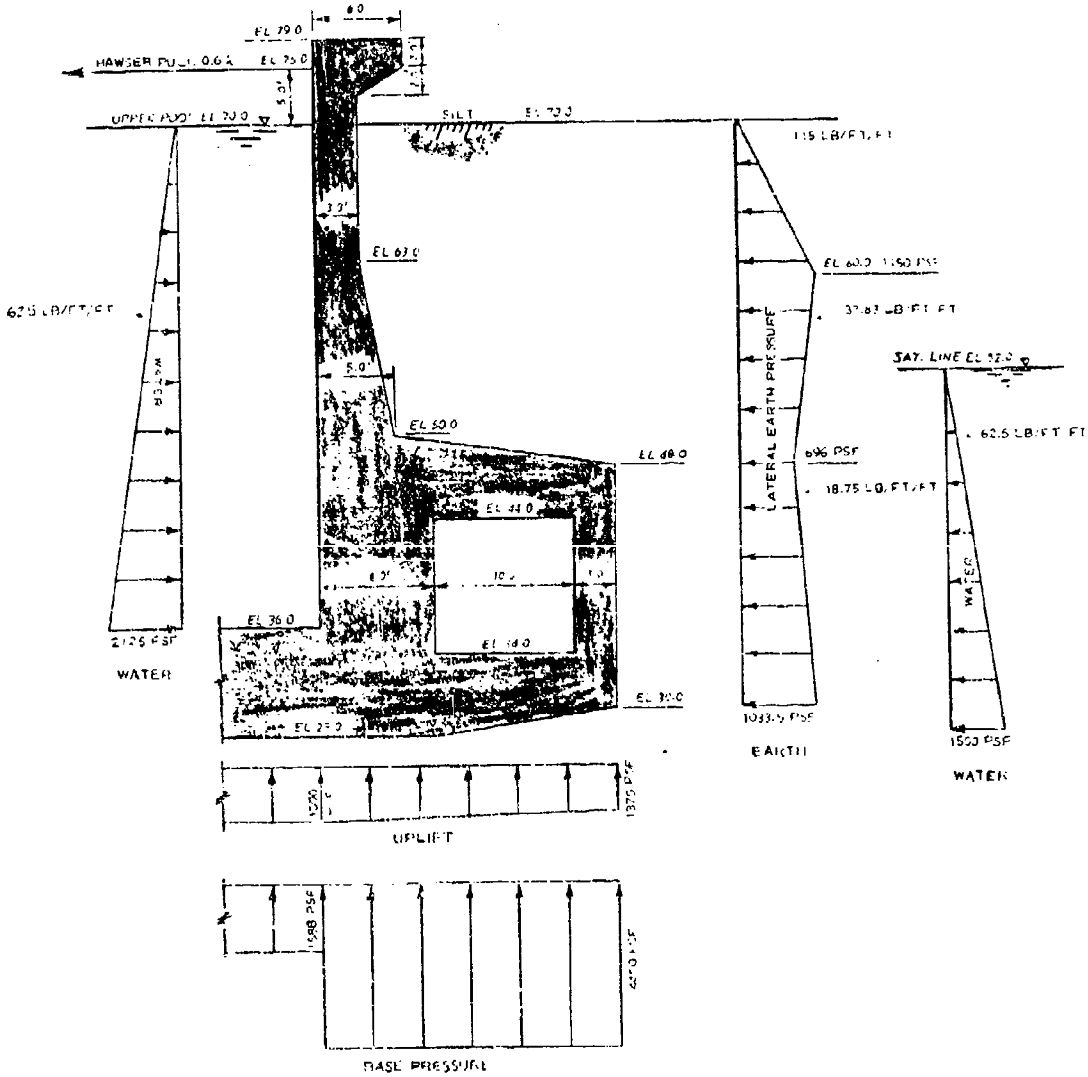

Figure 15. Conventional analysis - typical geometry and loading

PART V: CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are presented as a summary of the State of the Corps Art in U-frame lock analysis.

Conclusions

The author's conclusions are:

a. There is no universally accepted design procedure for U-frame lock monoliths (as discussed in Finite Element Method, Part III).

b. The beam on elastic foundation analysis does not yield acceptable results when applied to U-frame lock monoliths (as discussed in Beam on elastic foundation, Part III).

c. Conventional methods of analysis may be used to determine member sizes if foundation pressures and lateral pressure distributions are determined from previous instrumentation data or from good soil-structure interaction assumptions, such as those used by the Mississippi River Commission in the design of Port Allen and Old River Locks. Designs based on conventional analysis should be limit type designs with applied factors of safety. Conventional analysis can be most effectively used to preliminarily size members for use in the more sophisticated finite element U-frame codes.

d. The original U-frame finite element code is a two-dimensional analysis of a 1-foot section of a chamber monolith and because of numerous limitations and shortcomings, should be used with caution.

e. The modified U-frame code has eliminated many of the shortcomings of the original code and now includes the effects of axially loaded piles. It is a most sophisticated analysis, but still contains the basic fallacy of not considering the effects of cracking in reinforced concrete members. This code is also a two-dimensional analysis incapable of analyzing the more complicated three-dimensional monoliths. Despite its limitations it is the best analytical tool available.

Recommendations

The author's recommendations are:

a. Since all available computer codes contain certain limitations, the designer should use them with caution, always comparing

the results against logic and experience. Existing codes should be modified to consider the effects of cracking in reinforced concrete, and possibly be further extended to include analysis of three-dimensional monoliths.

b. The time required for input preparation, the degree of mesh refinement necessary to properly idealize the soil-structure interaction, the large amounts of computer storage and the computer run-time required for the finite element codes are excessive, and the use of such codes cannot normally be justified as a design tool.

c. To simplify input preparation, the Mesh generating routine discussed in Part III should be included in the modified U-frame code.

d. The author believes the State of the Corps Art for U-frame lock codes is not sufficiently advanced to receive widespread acceptance by the practicing engineer. As long as limitations are noted, existing codes do have merit as research tools to develop pressure distribution design charts based on variable chamber width, wall heights, loading conditions, etc., and relative member stiffnesses.

e. Since at least one U-frame monolith at both Felsenthal and Calion Locks will have instrumentation similar to that provided at Port Allen and Old River, every effort should be made to obtain a complete finite element analysis based on the modified U-frame code on each of these monoliths. These analyses should be obtained well in advance of construction, so that analysis results can be compared with field instrumentation results and thus bring the Corps closer to a universal acceptance of U-frame design techniques.

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NOTATION

A_s	Area of steel reinforcement
b	Width of beam
d	Structural depth of beam
f_c	Stress in concrete
f_{cc}	Stress in concrete under compression
f_{ct}	Stress in concrete under tension
f_s	Stress in steel
$fc'/2$	Compressive strength of concrete at 28 days
t	Depth of beam
ε_c	Strain in concrete
ε_{ct}	Strain in concrete under tension
ε_s	Strain in steel

U-FRAME CHANNELS

by

James W. Simmons*

General

U-frame channels, flumes, stilling basins, and connecting channels are rigid-framed reinforced-concrete structures with a typical rectangular or trapezoidal shaped cross section consisting of a base slab and two cantilevered walls. The walls are rigidly connected to each end of the base slab, and the thickness of the bottom of the walls is equal to the thickness of the base slab at the points of connection. The walls are generally tapered since the fixed-end moments at the base decrease. The base slab thickness may be constant or tapered and may project past the exterior face of the wall to form a heel to resist uplift.

Design Criteria**

The design loadings to be considered are:

a. Case 1. Construction and maintenance, with exterior earth pressure due to normal ground water and channel empty.

b. Case 2. Normal operation, with earth pressure due to normal ground water and low water level in the channel.

c. Case 2a. Normal operation plus earthquake.

d. Case 3. High water condition, with saturated soil due to high ground water on the outside of the channel and high water on the inside of the channel.

e. Case 4. Flood condition or extreme high water, saturated soil due to high water level on the exterior of the channel and water level on the inside of the channel at the top of the walls.

f. Case 5. Sudden draw down, saturated soil on the exterior of the channel due to the high water level and low water inside the channel.

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* Chief, Structural Section, Baltimore District, North Atlantic Division.

** Reference EM 1110-2-2400 (Nov 1964).

Design Procedures

The complete design may be separated into two phases: the design or selection phase and the analysis phase. In the first phase the thicknesses of the base slab and walls are computed or estimated, and the area of reinforcement is computed to resist the bending moments and compared to the minimum reinforcement required by EM 1110-2-2103. During the analysis phase a given section is subjected to a set of superimposed loads for stability. The moments, shear forces and shear stresses, the required steel area for reinforcement, and the wall displacements are computed.

Computer programs available can generally be divided into design types and analysis types.

State of the Art

The results of the Waterways Experiment Station (WES) survey made in June 1975 revealed that 25 districts in the Corps of Engineers were currently involved in the design of U-frame channels. Ten districts, or 40% of the total number of districts currently involved in U-frame channel design, indicated that they had used a computer program in their designs. The remaining 15 districts, or 60%, are designing U-frame channels using desk top calculators.

All districts that indicated on the questionnaire that they had used a computer program were contacted by phone, and a copy or write up of the program they were using was requested. Nine different programs were received as a result of the request. Five of these programs have been reviewed and evaluated. These five are:

a. U-Wall Reinforced-Concrete Channel Design, Program No. 713-F5-L3-001, from the San Francisco District.

b. Retaining Wall Design, Program No. 713-F5-C1-030, from the Kansas City District.

c. U-Frame Structure Design, Program No. 713-S8-K5-180, from the Mobile District.

d. EFFRAM - Analysis of Plane Frames on Elastic Foundations,

Program No. 713-DO-F7-110, from the New England Division.

e. Symmetrical U-Structure on an Elastic Foundation, Program No. 713-I1-F5-050, from the St. Paul District.

An abstract and evaluation of each program is included in this paper. In addition, the paper also contains an overall evaluation of computer usage for the design of U-frame channels by the Corps.

Three commercial computer vendors that sell time on their main frame computers were contacted and their involvement in the design of U-frame channels was investigated. None of the private computer vendors contacted had a specific program presently available for the design of U-frame channels, but all recommended the use of one of their general purpose programs as listed below for the design.

Computer Science Corp.	"SAGS"
Control Data Corp.	"2DGENFRAME"
McDonnell Douglas Corp.	"STRUDL"

U-WALL REINFORCED-CONCRETE CHANNEL DESIGN

713-F5-L3-001

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM U-Wall Reinforced-Concrete Channel Design	**PROGRAM NO.** 713-F5-L3-001
PREPARING AGENCY U.S. Army Engineer District, San Francisco, Corps of Engineers 100 McAllister Street, San Francisco, California	

AUTHOR(S)	**DATE PROGRAM COMPLETED**	**STATUS OF PROGRAM** PHASE	STAGE
J. D. Helmich	September 1969	INIT	REP

A. PURPOSE OF PROGRAM

This program provides a rapid method of design for a cross section of a reinforced-concrete U-walled channel. Also provided as an option is a plot routine for graphs of the reinforcing steel requirements of the channel.

B. PROGRAM SPECIFICATIONS

FORTRAN IV (H)

C. METHODS

The program utilizes a direct method of solution for the thickness and reinforcing steel requirements of the wall and an interactive solution for the geometry of the base slab. Elastic structural analysis is applied, calculated on the basis of a rigid structure on a rigid foundation.

D. EQUIPMENT DETAILS

IBM 360 (128k bytes) or GE 415 (32k words) or comparable configuration including card reader and printer, and an off-line keypunch for data preparation.

CID Incremental Plotter (for optional plotted O/P).

E. INPUT-OUTPUT

Input is via cards punched from input from SPN 540.

Output is via printer with an optional plot which graphically displays the maximum wall and slab steel requirements. Output consists of slab data, data for heel, soil pressure, and final concrete dimensions for channel.

F. ADDITIONAL REMARKS

Plot option is called by routines which are an integral part of the program. In order to use plot option, Benson-Lehner Plot software package with modifications is necessary. Request Program No. 803-F5-L3-000 (Plot Package).

Program evaluation number 1

Program Title: Reinforced-Concrete Channel Design.

Preparing Agency: U. S. Army Engineer District, San Francisco.

Reference Number: 713-F5-L3-001 also referenced as 713-G2-L3-001 and modified for he GE 635 by the Baltimore District Reference No. 713-F3-L3-001.

The program utilizes a direct method of solution for the thickness and reinforcing steel requirements of the wall and in an interactive solution for the geometry of the base slab. Elastic structural analysis is applied, calculated on the basis of a rigid structure on a rigid foundation.

The program is a design-type program. It is a very precise U-frame channel design tool for channels on a rock foundation. It is very easy to load and economical to run.

The program has been run at the Baltimore District on the Cowanesque Lake and Dam stilling-basin channel. The computer cost to make one complete run for a section of the Cowanesque stilling basin, with 40 ft 4 in. wide and 33 ft 6 in. high walls, was $1.59. A similar section done by an engineer using a desk top calculator averages four (4) man days.

This program has been approved, documented, and centrally filed in the Waterways Experiment Station (WES) Engineering Computer Programs Library (ECPL). Any interested party should contact the ECPL for further information.

RETAINING WALL DESIGN

713-F5-C1-030

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM Retaining Wall Design	PROGRAM NO. 713-F5-C1-030

PREPARING AGENCY Kansas City District, Corps of Engineers, ADP Center, 601 East 12th Street, Kansas City, Missouri 64106

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Marion M. Harter Byron E. Bircher	November 1964	Init	Rep

A. PURPOSE OF PROGRAM

This program designs cantilever and gravity walls. By structural and stability analysis, the minimum required thickness of concrete, area of tensile steel, and shear stress at any location in a T-wall, reversed T-wall or U-frame wall is obtained for a structure having an adequate factor of safety against any mode of failure. By stability analysis, the minimum dimensions of a gravity wall are obtained. Ultimate-strength analysis determines structural safety factors.

B. PROGRAM SPECIFICATIONS

The program is written in FORTRAN IV.

C. METHODS

EM 1110-2-2502

(ACI 318-63) Building Code.

D. EQUIPMENT DETAILS

The data processing system is a Honeywell G-437 with the following on-line equipment: card reader, 4-reel magnetic tape unit, and printer.

E. INPUT-OUTPUT

Input is on cards.

Output is by the printer.

F. ADDITIONAL REMARKS

Original program number: 13-R3-C107.

Documentation is available.

Program evaluation number 2

Program Title: Retaining Wall Design.

Preparing Agency: U. S. Army Engineer District, Kansas City.

Reference Number: 713-F5-C1-030.

This is a design-type program. It is a very extensive and thorough program. Design and review of T-walls, U-walls, and gravity walls are possible with this program. The Kansas City District has used the program to design approach walls and stilling basin structures for outlet works. Both a working stress and ultimate strength design are given in accordance with the 1963 ACI Code. Included are a basin cost estimate and a redesign optimum basin option. It is believed that the economic study included in the program greatly increases its value and generates additional interest in the program.

U-FRAME STRUCTURE DESIGN

713-S8-K5-180

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
U-Frame Structure Design	713-S8-K5-180

PREPARING AGENCY

U.S. Army Corps of Engineers, Mobile District

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
James B. Gaines, Jr. Malcolm J. Babb	1 Nov 67 Rev. May 72	Final	Oper

A. PURPOSE OF PROGRAM

The required function of the program is the design of the frame of a reinforced-concrete stilling basin. Forces to act on the stem of the structure include: water on both faces, submerged or moist earth on one face, the weight of the stem itself, and hydrostatic uplift. Reinforcing steel requirements are to be computed using the elastic load theory.

B. PROGRAM SPECIFICATIONS

FORTRAN IV

C. METHODS

The analysis of a structural section is essentially:

- a. Forces on the stem and their resulting moments about the outer face of the stem base.
- b. Required tensile steel, allowable bond, and required perimeter bars.
- c. Forces on the slab, foundation pressure, resulting moments, required tensile steel, allowable bond, and required perimeter of bars for three points on the centerline of the slab. The three points are the interior face of the stem, the centerline of the structure, and the exterior face of the stem.

D. EQUIPMENT DETAILS

Univac 1108
On-line Printer
Read/Punch

E. INPUT/OUTPUT

Input: Card
Output: Printer

F. ADDITIONAL REMARKS

Documentation is available.

Program evaluation number 3

Program Title: U-Frame Structural Design.

Preparing Agency: U. S. Army Engineer District, Mobile.

Reference Number: 713-S8-K5-180.

This program is a design type program. It is a very simple, precise U-frame structure design for channels on a rock foundation. It appears to be very easy to load and economical to run. Preliminary review of the program indicated that some refinement may be necessary before program can be used for final design.

EFFRAM - ANALYSIS OF PLANE FRAMES ON ELASTIC FOUNDATIONS

713-D0-F7-110

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
EFFRAM - Analysis of Plane Frames on Elastic Foundations	713-DO-F7-110

PREPARING AGENCY
U.S. Army Corps of Engineers, New England Division

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
P. R. Laliberte	July 1973		

A. PURPOSE OF PROGRAM

The program computes joint deflections and member-end forces for plane frames that are subjected to joint loads and joint displacements. The structure to be analyzed may be founded on an elastic foundation. The program will compute the bearing pressure (nonlinear) and will perform iterations to remove tension in the analogous spring foundation if desired.

B. PROGRAM SPECIFICATIONS

The program is restricted to 75 members and 55 nodal points.

The maximum nodal point difference is ten.

C. METHODS

Finite element techniques utilizing the direct stiffness method of matrix analysis are the basis for the program. The elastic foundations theory is based on Eduard Winkler's concept of analogous springs.

D. EQUIPMENT DETAILS

The program is written in FORTRAN IV and operates on a GE400 Series Computer with approximately 23,258 words of memory.

Peripherals include a card reader, a disc drive, and a page printer. System software include a date-time clock.

E. INPUT-OUTPUT

Input allows computations for any number of sections with any number of loadings. Output provides a listing of descriptive data for the plane frame, joint displacements, bearing pressures with location of compression and tension zones, and member-end forces.

F. ADDITIONAL REMARKS

1. Handles variable foundation conditions.
2. Foundation springs can be placed on any element.
3. Foundation springs may have one-or two-way action.
4. Foundation springs can be located on either side of the element by reversal of the I and J node numbers.

Program evaluation number 4

Program Title: EFFRAM - Analysis of Plane Frames on Elastic Foundations.

Preparing Agency: U. S. Army Corps of Engineers, New England Division.

Reference Number: 713-DO-F7-110.

This is an excellent analysis-type program that can solve plane frames up to 75 members and 55 nodal points. The method used is a finite element technique utilizing the direct stiffness method of matrix analysis. The program allows both nodal point loads and element loads to be entered as data. Input allows computations for any number of sections with any number of loadings. It can clearly be seen that this program has many other applications in addition to the analysis of U-frame channels.

SYMMETRICAL U-STRUCTURE ON AN ELASTIC FOUNDATION

713-I1-F5-050

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM		PROGRAM NO.
Symmetrical U-Structure on an Elastic Foundation		713-I1-F5-050

PREPARING AGENCY

St. Paul District, U.S. Army Corps of Engineers

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STAGE
Original Authors: R. L. Renner, W. M. Rankin - Omaha Revised: See Section F below	January 1970		

A. PURPOSE OF PROGRAM

The program will analyze a symmetrical, U-shaped concrete structure loaded symmetrically and supported on an elastic foundation. The shears, moments, deflections, and soil pressures required to design the structure are computed by this program.

B. PROGRAM SPECIFICATIONS

Program Language -- FORTRAN IV. No external storage required. This program is limited to analyzing a given section. If soil pressure or concrete stresses exceed allowable values, new trial dimensions must be chosen and another computer run must be made.

C. METHODS

The cantilever walls and floor slab are designed to act together as a monolith so that the loads on the walls combined with the loads on the floor slab produce a unique distribution of foundation reactions or pressures. In the analysis of the floor slab, the assumption is made that the foundation pressures are distributed in accordance with the theory of beams on elastic foundation. The theory was extensively developed by M. Hetenyi in his book, Beams On Elastic Foundation, from which the solutions of differential equations were taken to derive the equations used in the analysis.

D. EQUIPMENT DETAILS

IBM 1130 Model 2B, 8K including 1131-2B CPU with 2315 disk, 1132-1 line printer and 1442-6 card-read-punch.

E. INPUT-OUTPUT

The program requires input data specifying the geometry of the structure, the soil and water loading conditions, foundation modulus, and the modulus of elasticity of concrete.

Output consists of the shears, moments, deflections, and foundation pressures required to design the U-structure.

F. ADDITIONAL REMARKS

Original program revised in St. Paul District by: E. Kinnunen, M. Downs, and G. Cohen.

Write-up, flow chart and operating instructions are available from the St. Paul District ADP Center.

Program evaluation number 5

Program Title: Symmetrical U-Structure on an Elastic Foundation.

Preparing Agency: U. S. Army Corps of Engineers, St. Paul District.

Reference Number: 713-G1-F5-050.

This program is an analysis type, limited to analyzing a given section. It appears to be up to date. The program analyzes U-frame channels on elastic foundations. In the analysis of the floor slab, the assumptions are made that the foundation pressures are distributed in accordance with the theory of beams on elastic foundation. The estimated run time is 5 minutes, which makes it very economical.

This program has been approved, documented, and centrally filed in the WES ECPL. Any interested party should contact the ECPL for further information.

Computer Usage for Design of U-Frame Channels by the Corps of Engineers

It is evident that it is more economical to design U-frame channels with the use of computer programs than it is to use desk top calculators or other methods presently available. Through the use of an applicable computer program, a more refined and more economical design will more likely be realized; and design time will be considerably reduced.

The evidence from the research revealed that only forty percent of the districts involved in U-frame channel design are presently using computer programs in their design. The reasons that the majority of the districts are still designing U-frame channels by other methods are believed to be:

a. Documentation of computer programs has not kept up to date with program developments.

b. Tight design-completion schedules have limited time for research for available computer programs.

c. Many designers feel that the design of U-frame channels is very simple and straightforward and that the status quo is adequate; therefore, they believe that the potential benefits of research to improve the present design methods are not worth the effort.

The programs presented in the report are believed to be the best and most complete programs presently available in the Corps for the design of U-frame channels. Additional information on the attached programs may be obtained from the original preparing agencies or contact James W. Simmons, Baltimore District, U. S. Army Corps of Engineers, P. O. Box 1715, Baltimore, Maryland 21203.

APPENDIX A: BIOGRAPHICAL SKETCHES OF AUTHORS

Norman W. Wilke is a structural engineer for the Walla Walla District, Walla Walla, Washington. He earned a Bachelor of Science degree from Oregon State College in 1958.

Charles M. Hargett is a Supervisory Structural Engineer and the Chief, Inspection and Evaluation Section, Vicksburg District, Vicksburg, Mississippi. He earned a Bachelor of Science in Civil Engineering from Louisiana Technical University in 1962, and his Master of Science in Civil Engineering (structures) from Purdue University in 1970. Before coming to the Vicksburg District in 1965, he worked for three years with the Bureau of Public Roads in the field of highway design. Mr. Hargett has written, developed, and/or implemented many computer programs. He has conducted lectures and workshop sessions in the practical application of the Finite Element Method and has written nine papers, including a technical report and a journal article.

James W. Simmons is a Supervisory Structural Engineer and the Chief, Structural Section, Baltimore District, Baltimore, Maryland. He earned a Bachelor of Science in Structural Engineering from Tennessee State University in 1955. Before coming to the Baltimore District in 1969, Mr. Simmons worked as a Structural Engineer for the Boeing Company and served the Seattle District as a Structural Engineer and Chief, Structural Section. His awards include the Quick Reserve Medal for flood-control work during Hurricane Agnes and the Sustained Superior Performance Award.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ... held in New Orleans, Louisiana, 22-26 September 1975] Vicksburg, Miss., Automatic Data Processing Center, U. S. Army Engineer Waterways Experiment Station, 1976-
12 v. illus. 27 cm.
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